NPS MDP Study
Outbrief Schedule, 1 JUN 2005

0800-0815 Introduction

0815-0915 Background/Results

0930-1015 Cargo Inspection System (Land)

1030-1130 Cargo Inspection System (Sea)

1130-1230 **LUNCH**

1230-1330 Sensors System

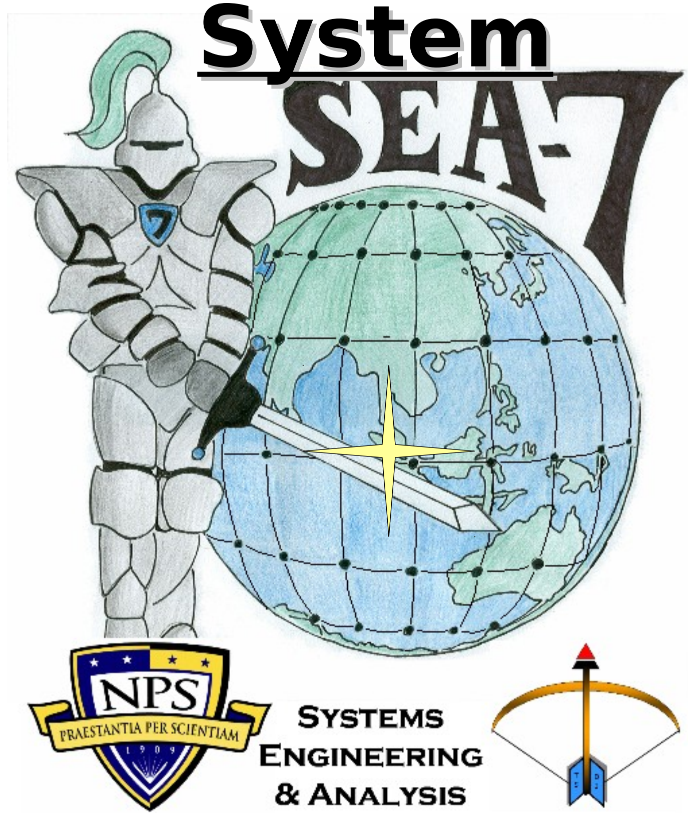
1345-1445 C3I System

1500-1600 Response Force System

NPS Cross-Campus Integrated Study

"Maritime Domain Protection in the Strait of Malacca"

Sensors System



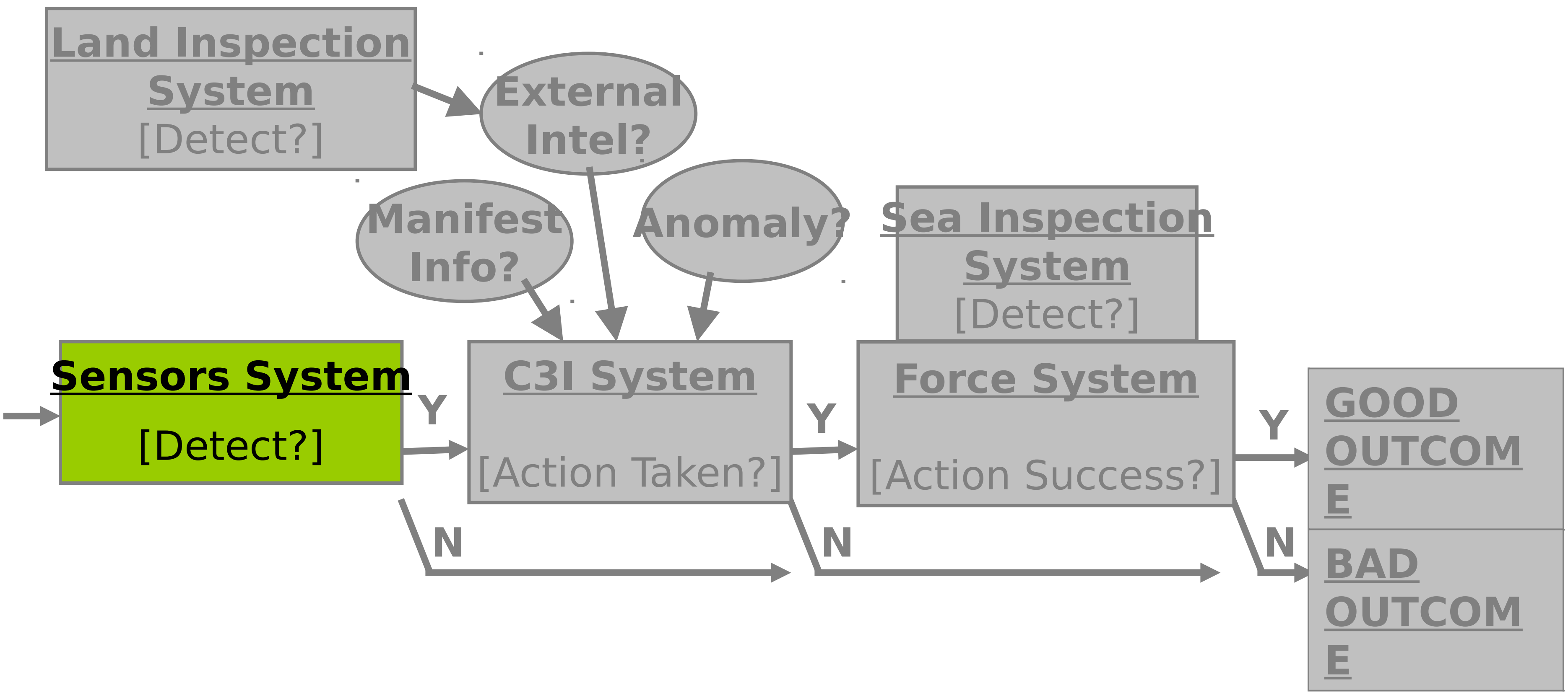
Presented by: LTC Guillermo Ferraris, ARG

Outbrief 1 June 2005

Sensors Agenda

- Introduction
- Objectives
- System Requirements
- As-Is System Description
- Alternative Generation
- Model Overview
- Assumptions
- Parameters/Factors
- Modeling Results
- Conclusions/Insights
- Recommendations
- Q&A

MDP System
Operational Architecture

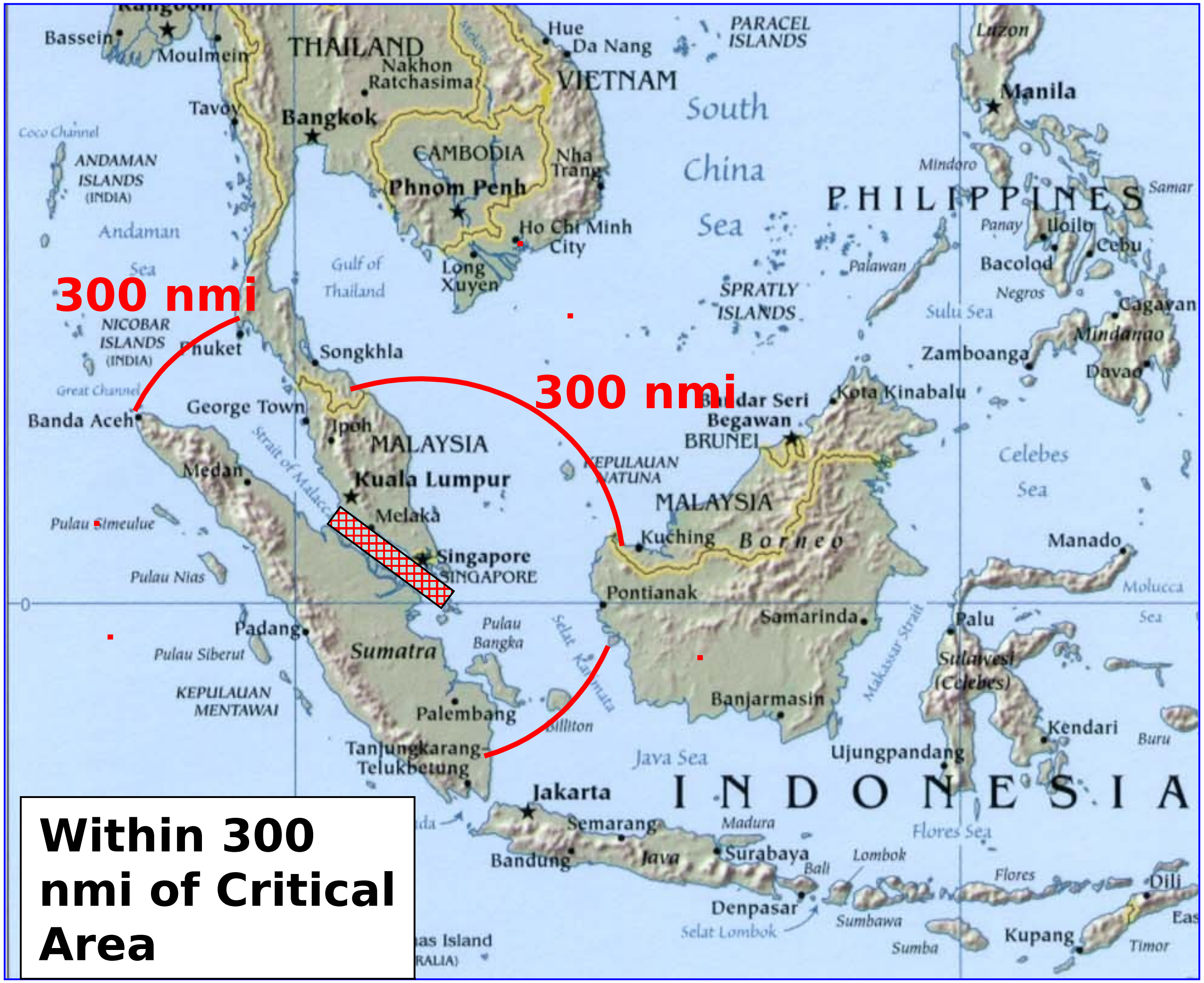


Sensors Group Objectives

Design a sensors system capable of providing "a persistent, real-time, all-weather capability to detect, track and classify/ID all defined contacts of interest (COI) within the area of regard (AOR) to support situational awareness and C2".

- **Determine optimal combination of sensors/platforms.**
- **Determine critical performance parameters for sensors/platforms (characterization of threats and environment).**
- **Determine architectural level "layout" (coverages, sites, number and type of sensors, operational profiles, interfaces, etc.).**
- **Perform analysis and evaluation through modeling and simulation.**
- **Perform "Cost-Benefit" and "Sensitivity" analysis.**

Sensors Area of Regard (AOR)

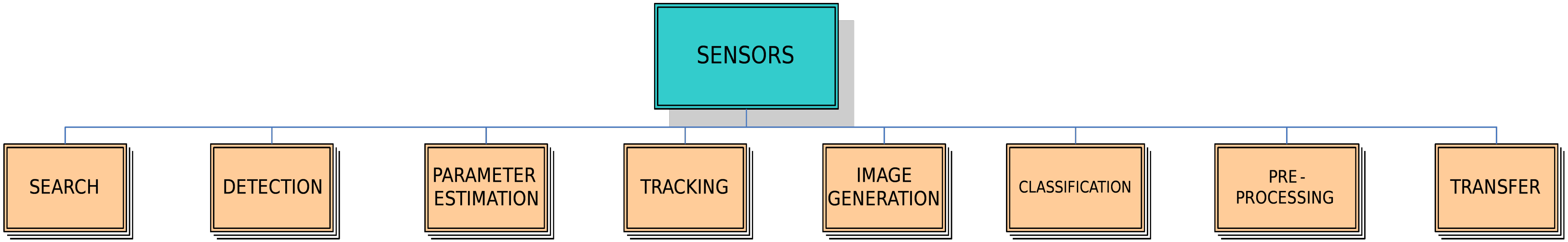


Within 300 nmi of Critical Area

Sensors System Requirements

- **Sensitivity (minimum detectability requirements)**
  - Locate and track 99.9% of “large ships” (≥ 300 GRT) in entire AOR.
  - Locate and track 80% of “small boats” (≥ 7m length) in Critical Area.
- **Range/coverage requirements**
  - Range: See definition of AOR (Critical Area & Approaches)
  - Coverage: overlapping coverage within AOR
- **Accuracy of measurements requirements (position)**
  - SAW (large ship): 50m CEP
  - SBA (small boat): 10m CEP
- **Time Latency requirements**
  - “Ability to meet C2 decision cycle timing constraints”

Functional Decomposition



DETECTION: An object of potential interest is present or absent in the sensing volume of the system.

CLASSIFICATION: The broad class of object types to which the object belongs may be determined.

IDENTIFICATION: The specific object type within a class of objects may be determined.

(INTENT DETERMINATION): Probable Hostile/Non-Hostile intent may be established.

As-Is Sensors System

The Current System

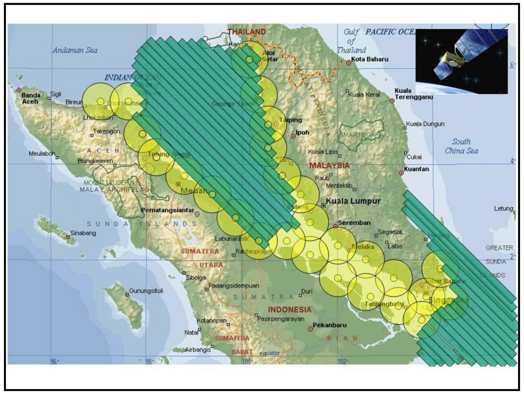
- 12 radar remote-stations
  - 7 Malaysia – X/S band
  - 5 Singapore – X band
- 3 VTS authorities
  - Kelang
  - Johor
  - Singapore
- 7 AIS base stations in Malaysia.
- 2 AIS base stations in Singapore Straits
- Several different MPA and patrol vessels
- Ship's own sensors (radar and AIS)

Alternative Generation

Platform	Sensor Type	Connectivity	AOR Coverage	Sensor Trigger Mode	Data Transmission Mode	Data Fusion Functions	Coverage (footprint)
Ground- (fixed-installation) (semi-fixed-installation)	Conventional Radar (MW – OTHR)	Stand-Alone	Integral	Autonomous	Synchronous (broadcast)	Distributed between sensors and fusion node	Broad area (surveillance)
Air- (manned) (MPA) (unmanned) (high altitude aerostats) (tethered aerostats) (UAV)	Imaging Radar (MW)	Fully Networked	Sectorized	Cued	Interrogate/ Respond (polling)	Centralized at fusion node	Limited area (surveillance)
Sea/Surface- (fixed-installation) (semi-fixed-installation)	Laser Radar	Clustered				Hybrid	Strip-Swath (Surveillance)
Sea/Subsurface- (fixed-installation) (semi-fixed-installation)	Conventional Sonar						Spot (Reconnaissance)
Space- (new constellation) (existing constellation) -military -commercial	Imaging Sonar						
Land- (fixed-installation) (semi-fixed-installation)	EO-IR						
Mobile- (multiple platforms)	ESM						
	Transponder/ Beacon						

Other Sensors Alternatives

SBR



HAEAR

CRITERIA / ALTERNATIVE	Performance	Technology Risk (*)	Cost	Schedule
MICROWAVE + SBR				
HAEAR				

Alternatives Overview

Primary Detection & Tracking Assets

ALTERNATIVE 1:

- **Coastal Radar Stations (X-band)**
- **HFSWR**

ALTERNATIVE 2:

- **Medium Altitude-Endurance Aerostat Radar (MAEAR)**
- **MPA**
- **HFSWR**

Augmentation Assets (Class/ID)

- **Automatic Identification System (AIS)**
- **EO-IR (MPA)**

Alternative Exploration Studies

- **UAVs for HVU Protection**
- **Non-Material Solutions - Naval Simulation System (NSS)**

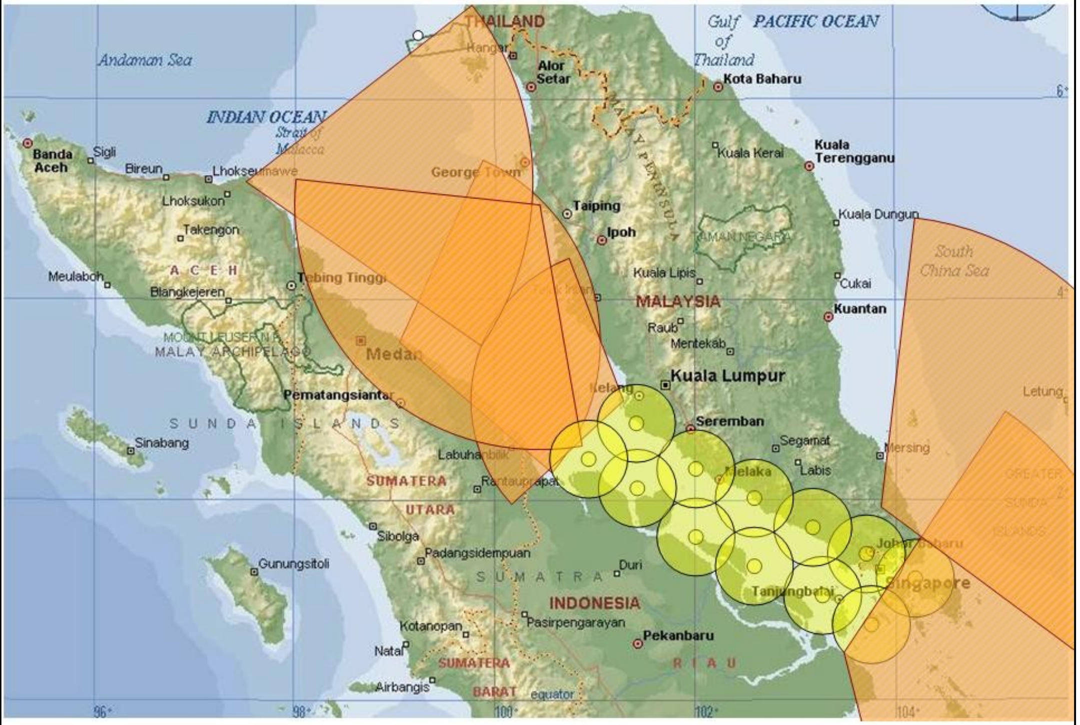
Sensors Alternative 1

Coastal Radar Stations (X-band) + HFSWR

- 14 radar remote-stations (X-band)
  - 400 ft towers (AM/TV broadcast+)
  - 25 nmi range

- 8 HFSWR remote stations
  - 200 nmi range
  - 120 deg coverage

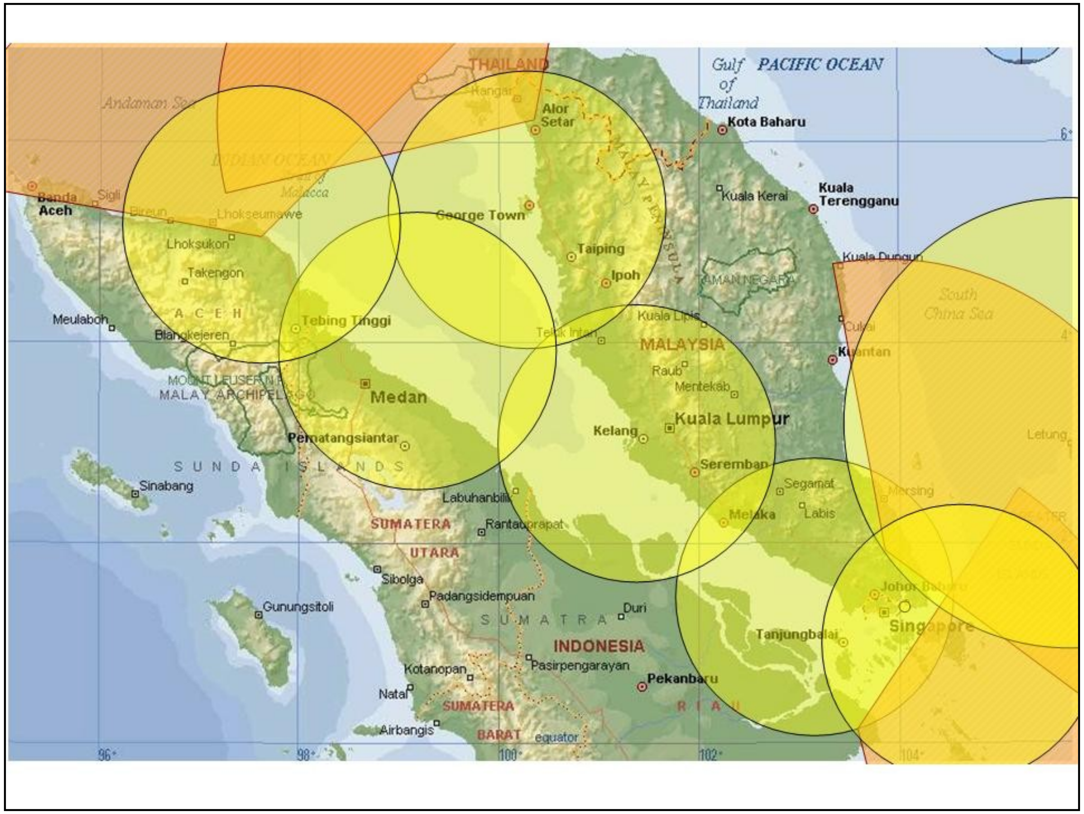
- AIS base stations co-located



Sensors Alternative 2

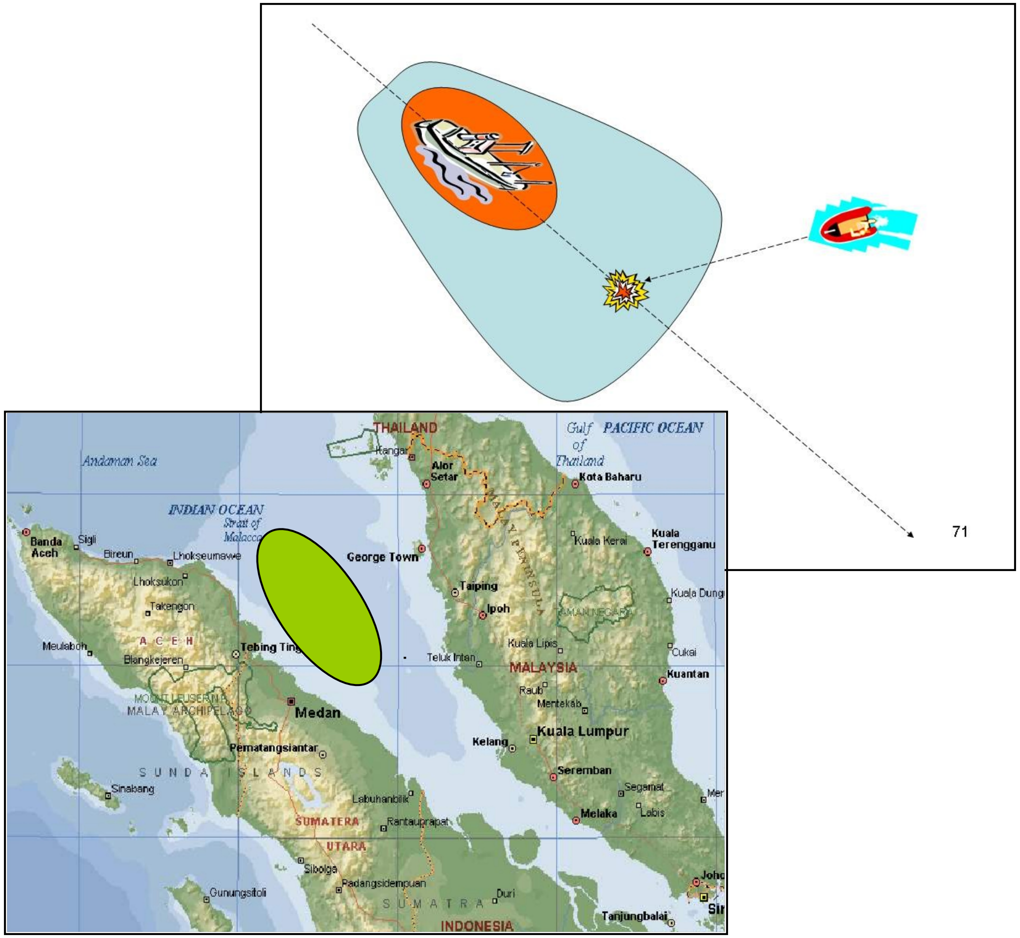
Medium Altitude-Endurance Aerostat Radar (MAEA + HFWSR

- Tethered aerostats (X-band radar)
- 6 aerostat sites at 5,000 ft
  - 90 nmi range
- 1 aerostat site at 15,000 ft
  - 150 nmi range
- AIS base stations co-located
- MPA for downtime (4 A/C)
- 6 HFSWR remote stations



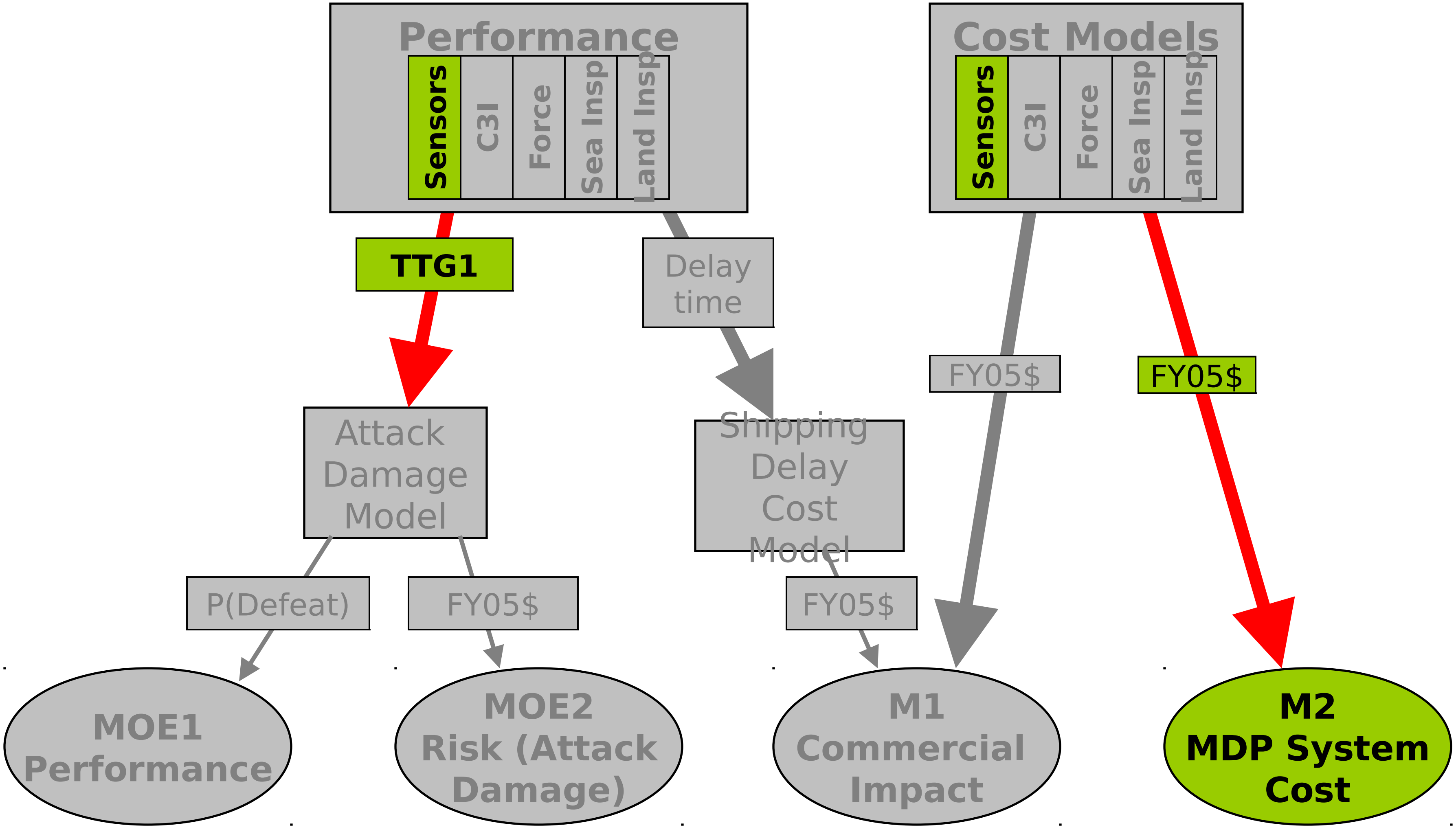
UAVs for HVU Protection

- Explore use of a UAV platform to monitor/classify potential targets around a HVU.
- Develop model to estimate optimal performance tradeoffs (max. coverage - min. number of UAVs).
- Area of Responsibility: NW approach to the strait.

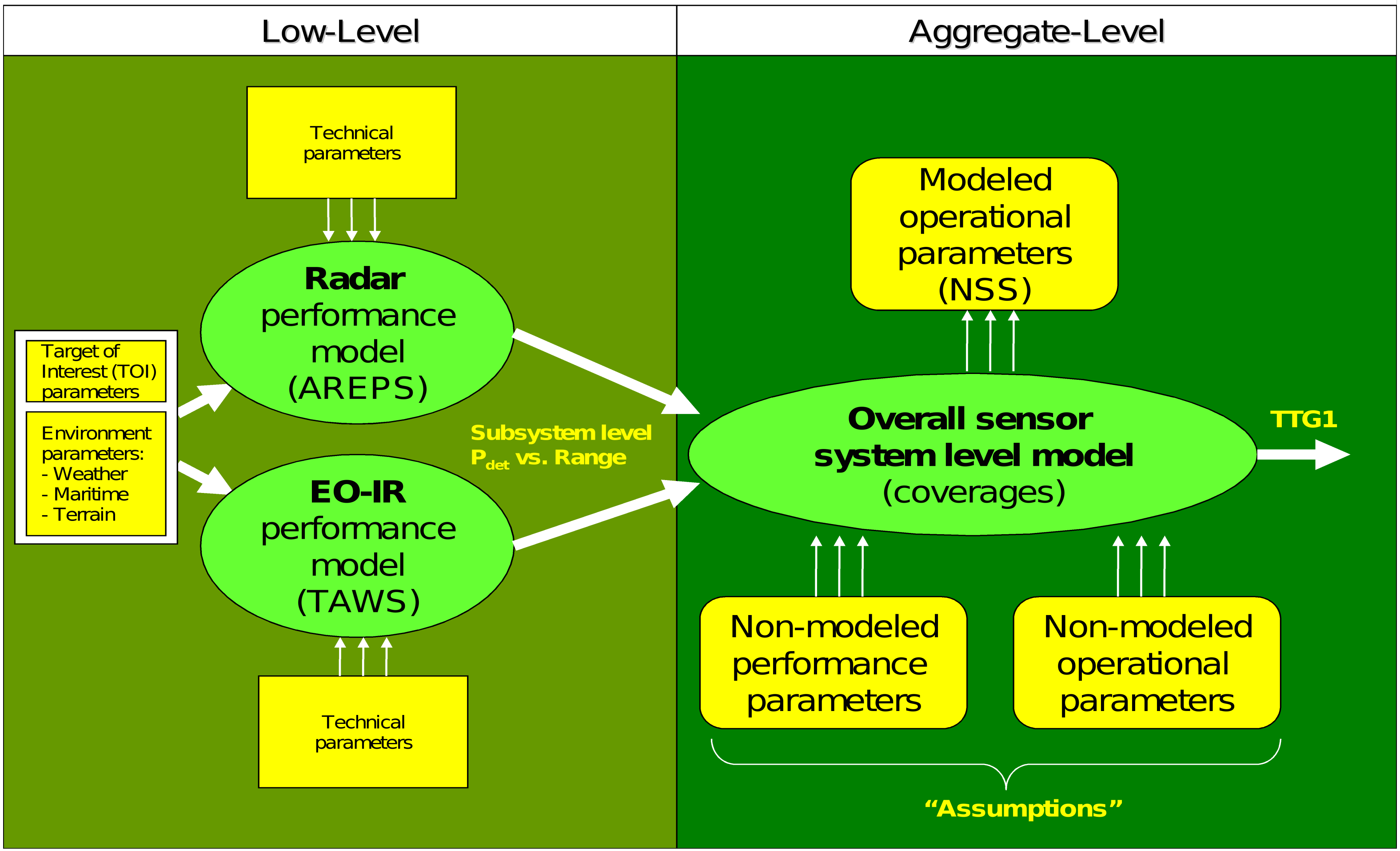


Modeling

Overarching Modeling Plan



Model Description



Modeling Assumptions

LOW-LEVEL

- **DIFFERENT SENSOR- AND ENVIRONMENT-SPECIFIC ASSUMPTIONS.**

AGGREGATE LEVEL

- **“COOKIE-CUTTER” SENSOR DETECTION MODEL.**
- **ALL LARGE SHIPS (>300 GRT) WILL HAVE OPERATIONAL AIS TRANSPONDERS.**
- **WORST-CASE FOR TTG1 CALCULATIONS.**

Modeling Factors

	Sensor-specific Parameters	Weather	Target Size	Platform Height	Other
Low-Level (AREPS)	• **Frequency (HF- and X-band)** • P_{fa} • Other	• **Surface duct** • **Evaporation duct** • **Standard**	• **4 m² RCS** • **800 m² RCS**	• **90 ft** • **400 ft** • **3,000 ft** • **5,000 ft** • **15,000 ft**	• **Sea state** • **Day/Night**
Low-Level (TAWS)	• Wavelength **- LWIR** **- MWIR** **- VIS (TV)** • MRT-MDT • Other	• **Precipitation** • Sea surface and air temp • Wind • Cloud • **Visibility**	• **Small boat** • **Large ship**	• **90 ft** • **1,000 ft**	• **Day/Night** • Surface aerosol & contaminants

Modeling Results

Low-Level Modeling

MICROWAVE MARITIME SURVEILLANCE RADAR

Presenter: Matthew Tong, TDSI - SG

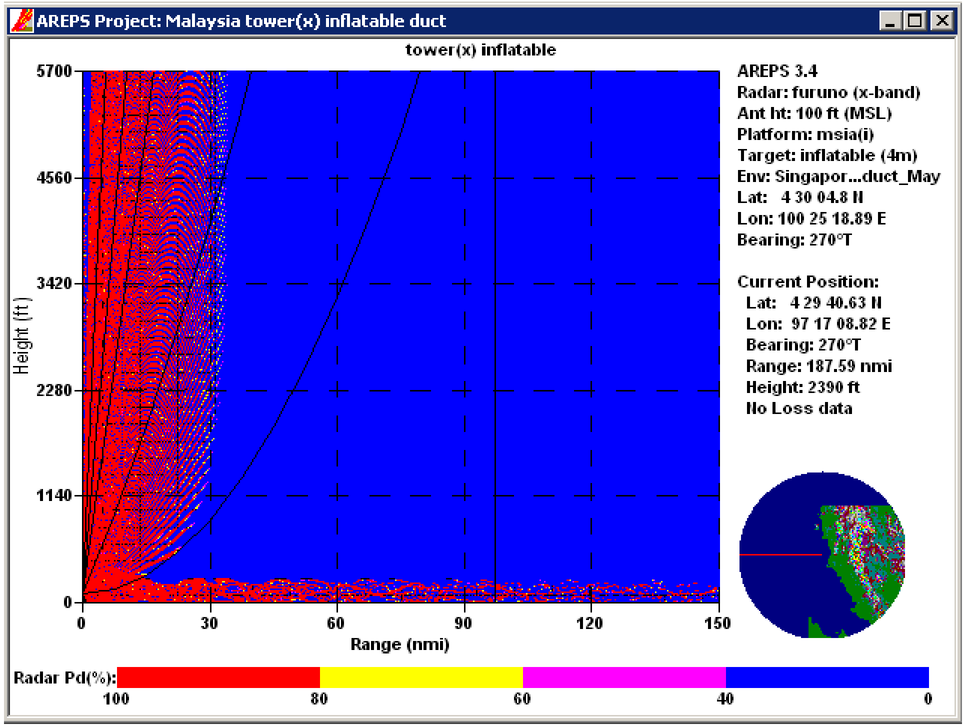
AREPS (Radar Model)

Advanced Refractive Effects Prediction System

- **Tactical decision aid for performance assessment of electromagnetic (EM) systems.**

- **EM propagation modeling of environmental effects on radiated frequencies from HF (2 MHz) to infrared (300 THz).**
  - **Spatial variations - in atmosphere and terrain.**
  - **Platform - Surface, airborne.**

- **Radar, communications and weapons performance assessment.**
  - **Probability of detection**
  - **Probability of**



<u>Purpose</u>:
- **Investigate and predict the detection performance of microwave radars and HFSWR radars along the Straits of Malacca.**

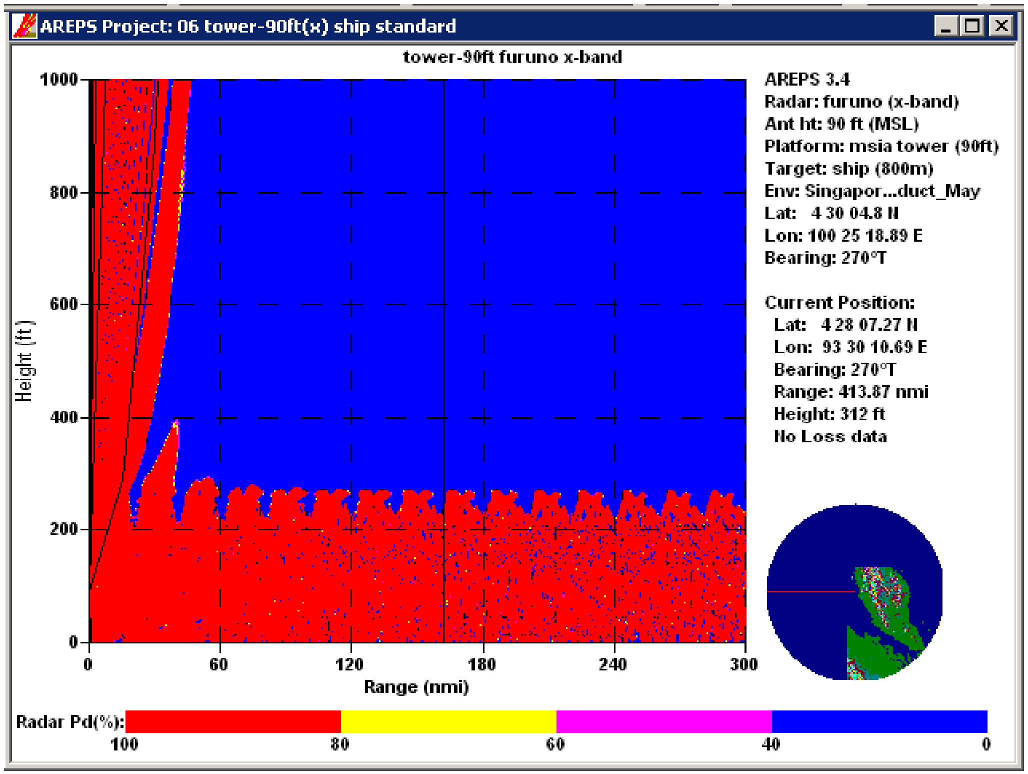
Space and Naval Warfare Systems Center
Atmospheric Propagation Branch, 2858

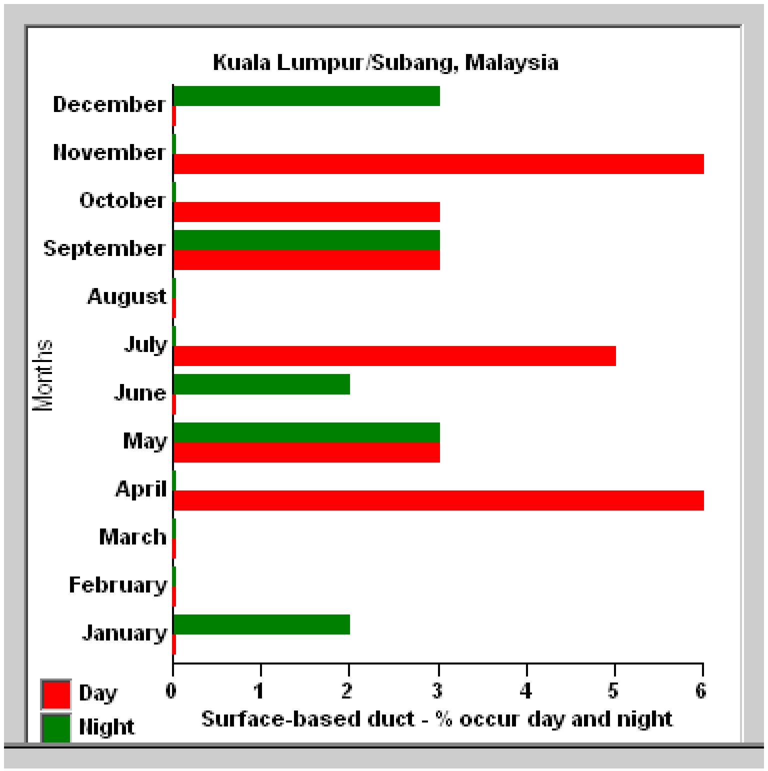
In collaboration with:
Professor Kenneth L. Davidson & Professor Peter Guest, Department of Meteorology, NPS, and Space and Naval Warfare Systems Center, Atmospheric Propagation Branch

Atmospheric Ducts in the Straits of Malacca

Surface-Based Ducts

- **Appears to extend detection ranges for *X-band* radars mounted on *coastal towers (height ≈ 90 ft)* searching for *surface targets*.**
- **BUT infrequent and unpredictable (typically occurs 15% or less of the time).**

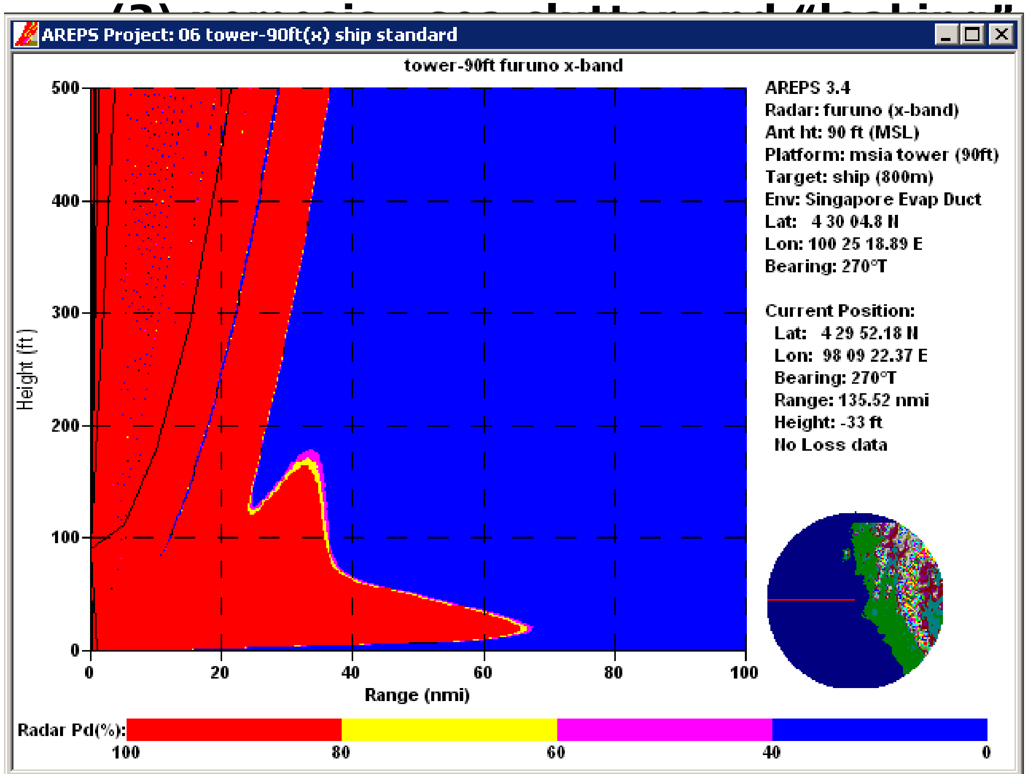


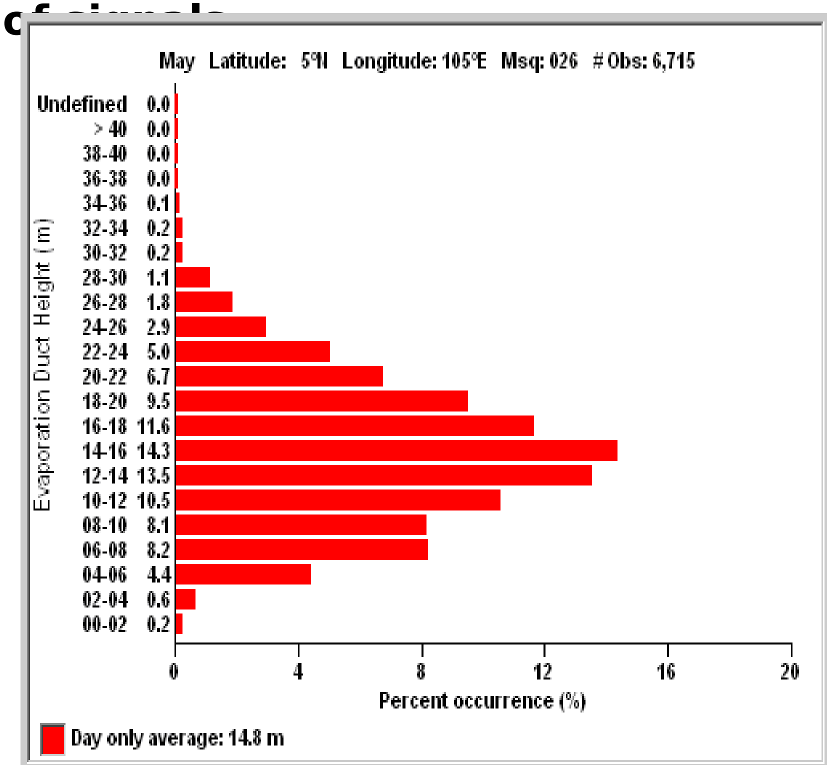


Atmospheric Ducts in the Straits of Malacca

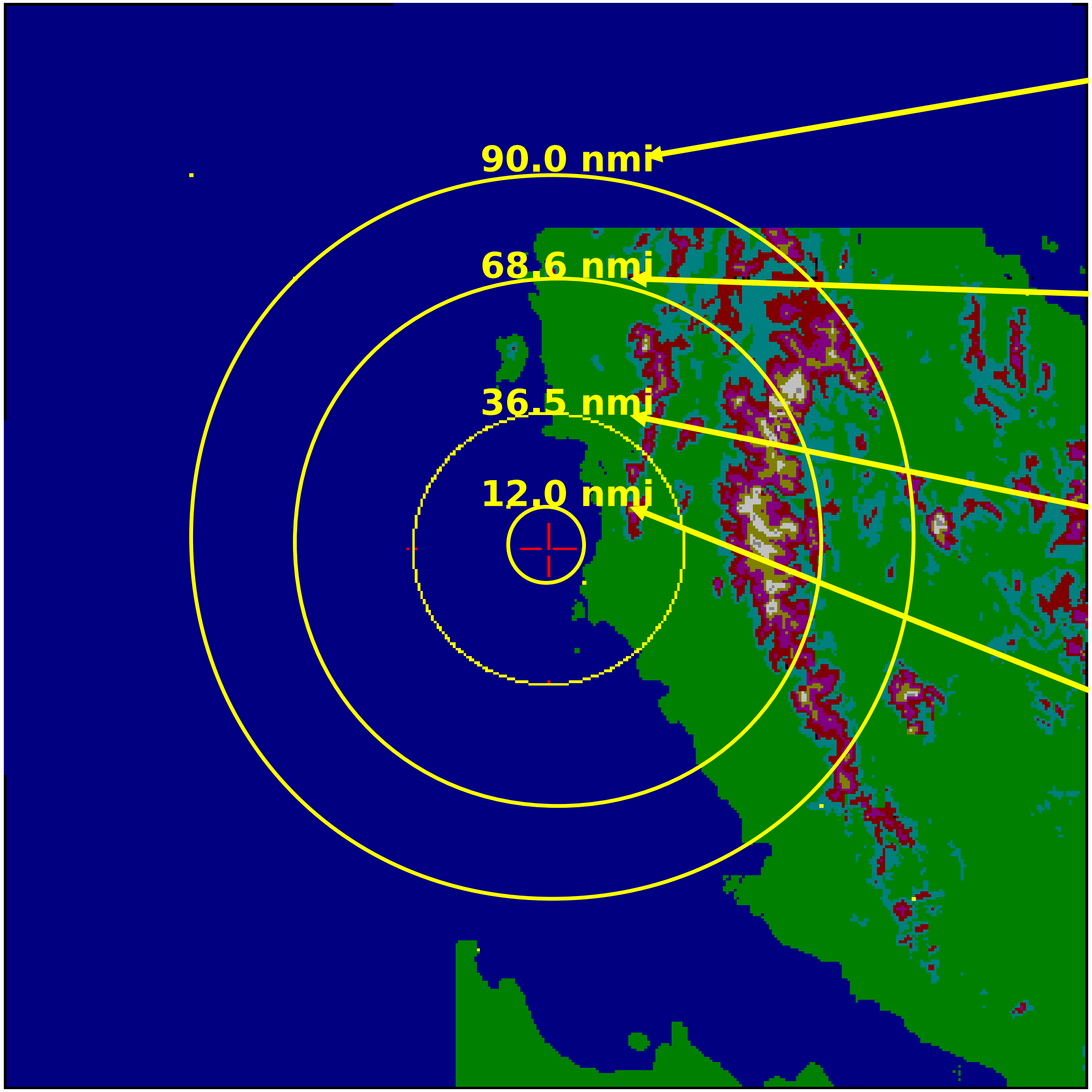
Evaporation Ducts

- **Appears to extend detection ranges for *X-band* radars searching for *surface targets:***
  - **Detection range depends on height of antenna relative to duct.**
  - **Exact frequency depends on height of duct.**
- **Evaporation ducts almost always exist over the Straits of Malacca.**
- **But (1) height varies and is difficult to predict/measure.**
  (2) goes against conventional wisdom (lower radar, longer range?).
  (3) nemesis – sea clutter and “leaking” of signals





Predicted Performance of Microwave Radars in the Straits of Malacca



High Altitude Coastal Surveillance (Proposed)
- APS-143 (X-band)
- Aerostat (5,000ft)

Mobile Coastal Surveillance (Existing)
- APS-137 (X-band)
- Maritime Patrol Aircraft (3,000 ft)

Low Altitude Coastal Surveillance (Proposed)
- SCANTER 2001 (X-/S-band)
- Coastal Tower (400 ft)

Low Altitude Coastal Surveillance (Existing)
- Furuno (X-band)
- Coastal Tower (90 ft)

- RCS= 800 m^2
- P_{Det} (single scan) = 0.90
- P_{FA} (single scan) = 1 x 10^{-8}.
- No temperature inversion.

AREPS - Findings & Recommendations (I)

- **Microwave radars are a “ready” solution to provide all-weather, continuous coastal surveillance in the Straits of Malacca.**
- **“Height-of-the-Eye” – main factor limiting performance. Hence, focus on platform is important.**
- **Surface-based ducts and Evaporation ducts over the Straits of Malacca can extend the detection ranges of microwave radars but are difficult to predict or exploit.**
- **Possibility of exploiting evaporation ducts using low or variable height antennas to extend the detection range of microwave (>3GHz) radars.**
- **Need to further study impact of electromagnetic interference from high density shipping on the operation of a large network of microwave coastal surveillance radars.**

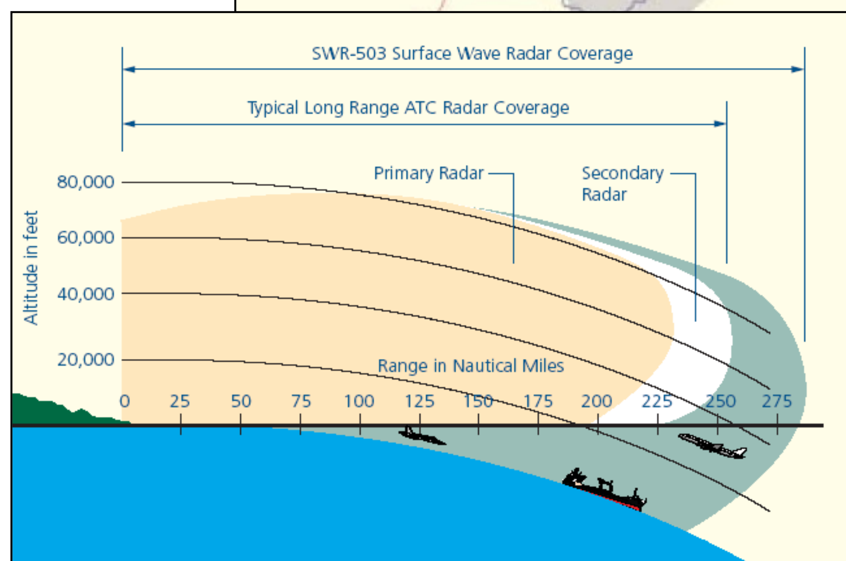
HIGH FREQUENCY SURFACE WAVE RADAR (HFSWR)

Presenter: Winston Ong, TDSI - SGP

HFSWR Modeling

• Raytheon’s SWR-503 system installed on Canada’s east coast, where it is being used to demonstrate continuous, all weather surveillance to ranges beyond 200nm.

• The SWR-503 primary operating frequency is between 3-5MHz.



Purpose

• Investigate suitability of employing HFSWR in the Straits of Malacca.

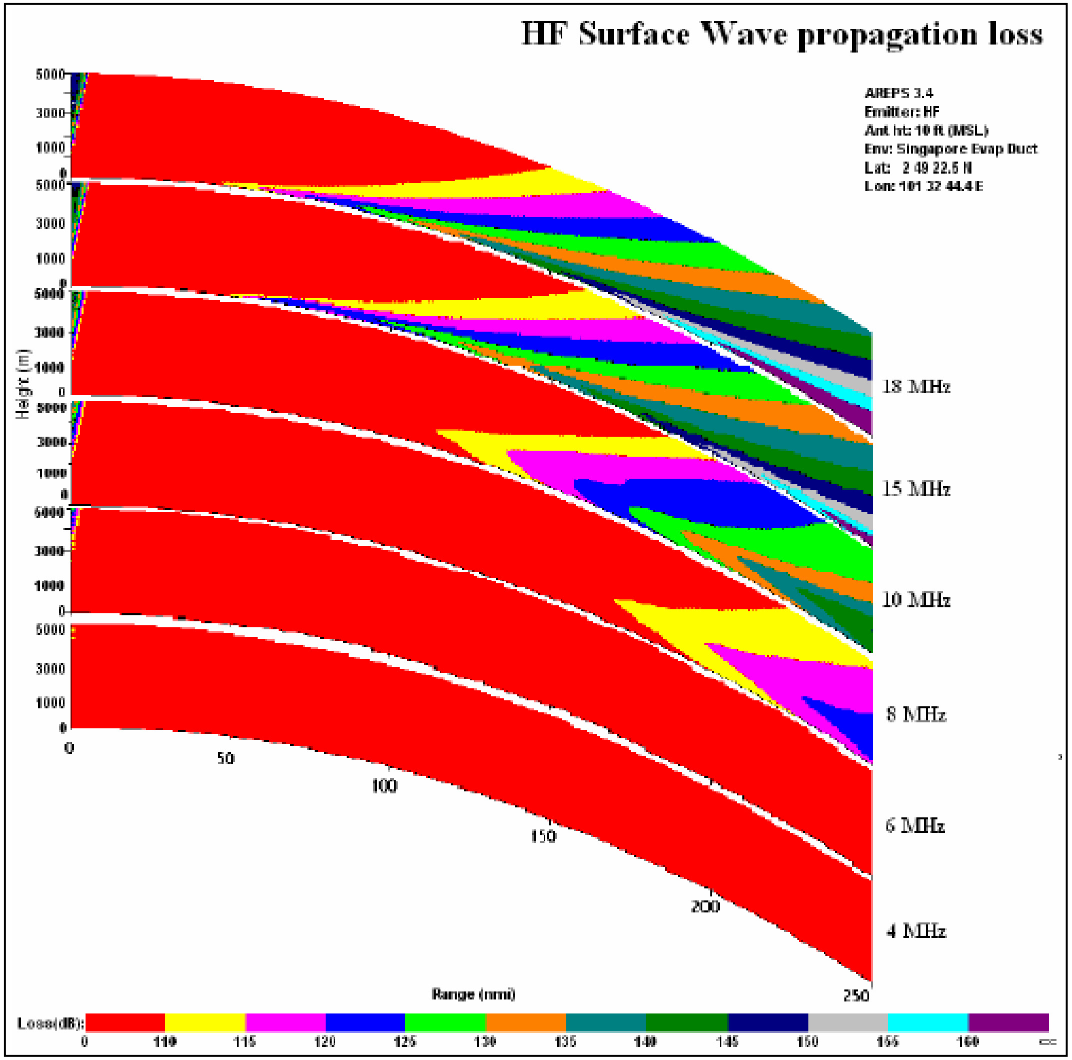
Information taken from Raytheon’s product brochure at http://www.raytheon.com/products/swr503/ref_docs/swr_503.pdf. p. 3

HFSWR Modeling

Modeling Results

• AREPS predicts efficient propagation in the range of 3-5 MHz to 200 nmi+.

Note: AREPS predictions should be taken as indicative for the type of losses experienced by HF radar (double the values to account for two-way propagation).



HFSWR Modeling

Skywave Interference in the Straits of Malacca

From AREPS prediction:

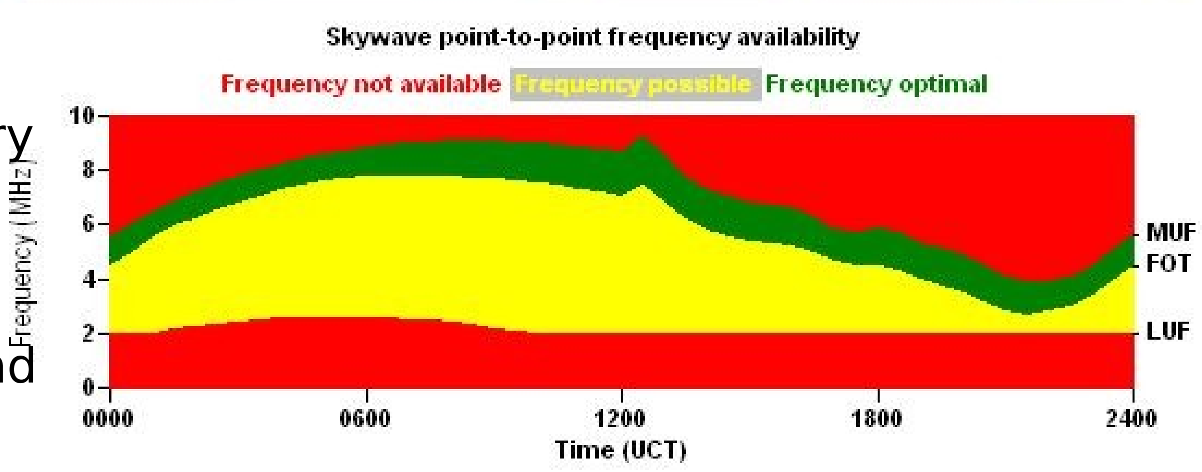
• 3-5 MHz band will be greatly affected by skywave interference during night time.

• Above10 MHz, skywave interference is not a major concern.

Trade-off

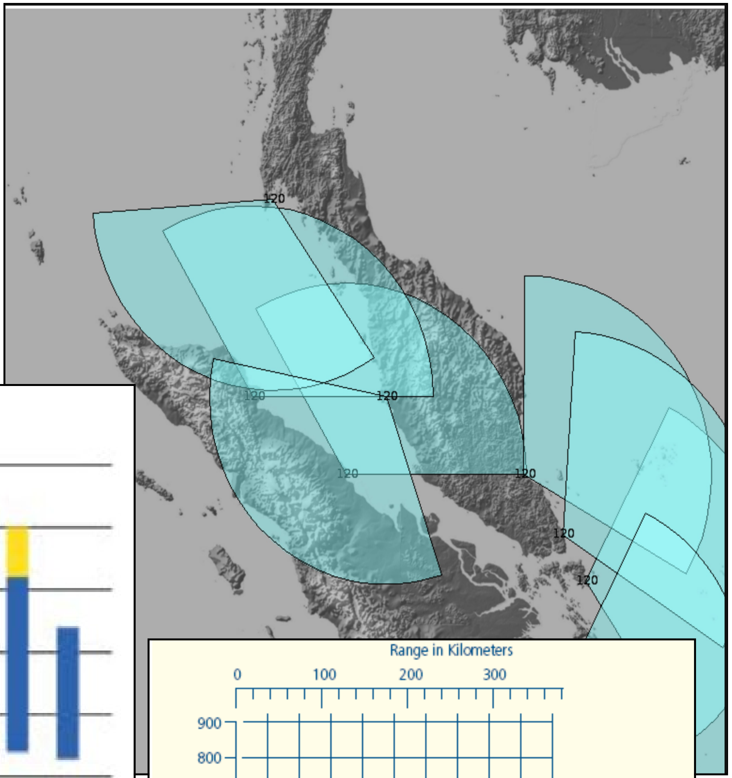
• 3-5 MHz band is optimal for long range (lowest attenuation) but is also very vulnerable to skywave interference.

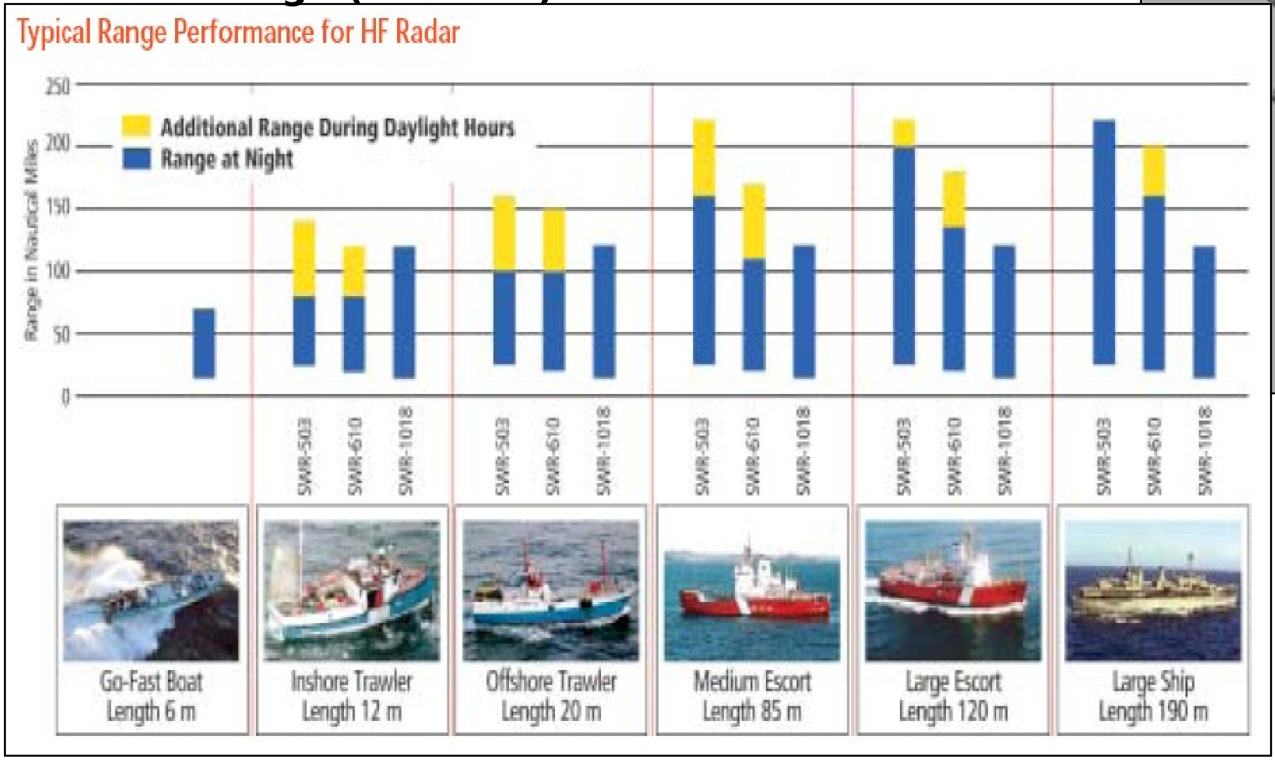
(Advancements in noise and interference cancellation technologies will continuously bring about better tolerance against interference)

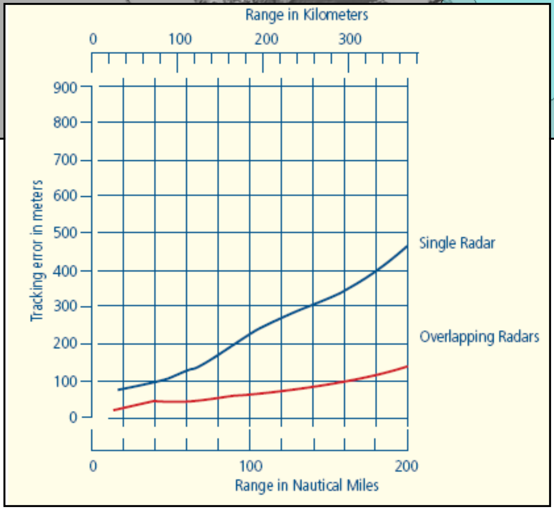


AREPS - Findings & Recommendations (II)

- With overlapping HFSWR coverage, the tracking error can be substantially reduced.
- For mid range, the use of higher band (10-18MHz) provides better detection performance against smaller targets.
- Long range (>150nm): 3-5MHz
  Mid range (<150nm): 10-18MHz







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ELECTRO-OPTICAL AND INFRARED SENSORS

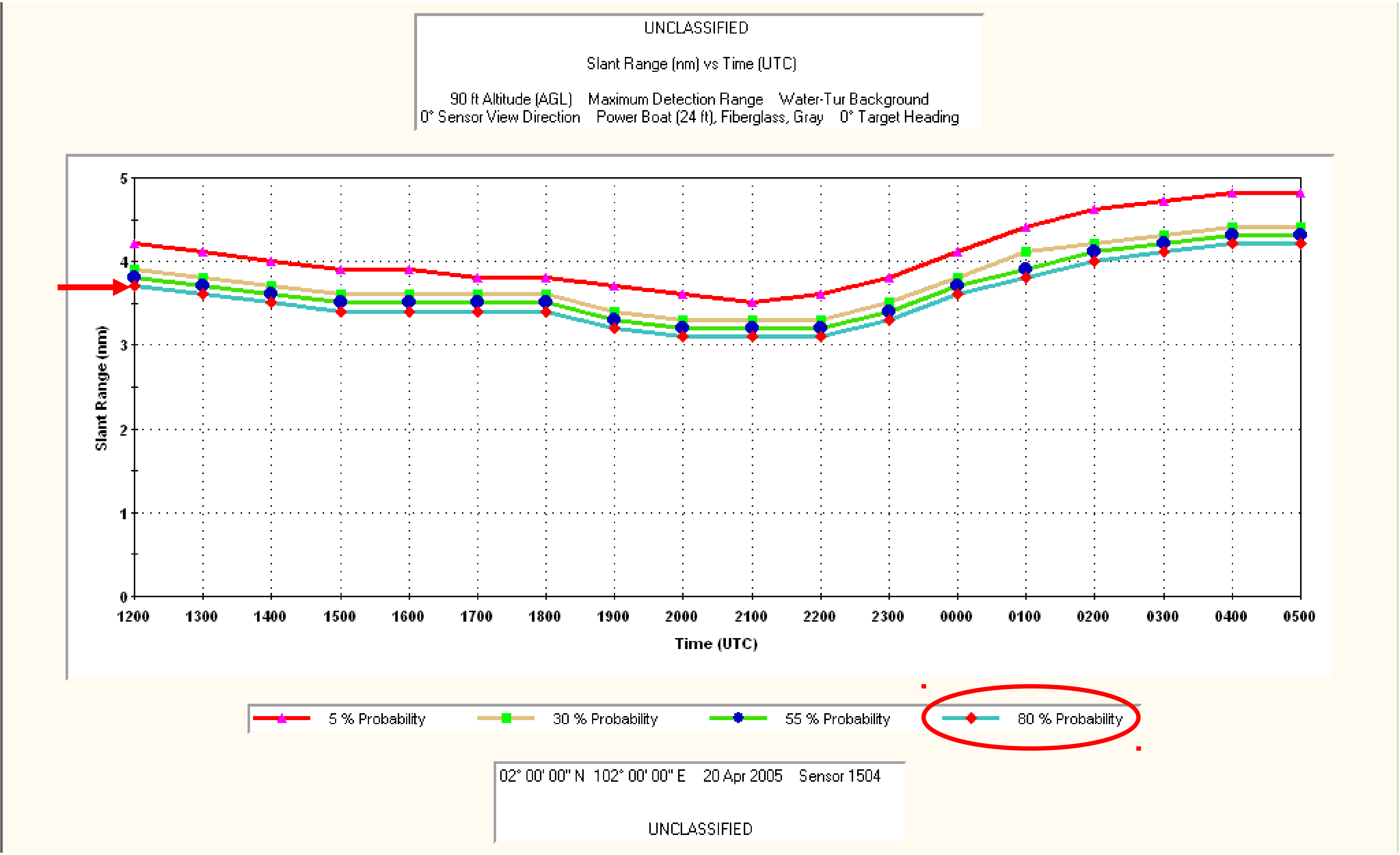
Presenter: Mark Tan, TDSI - SGP

TAWS (EO-IR Model)

Target Acquisition Weapons Software

- **Purpose**:
  - Investigate EO-IR sensing performance against defined targets in the AOR using local weather inputs.
- **TAWS**:
  - A weather impact tactical decision aid.
  - Predicts performance of EO-IR systems against weather/atmospheric, temporal and target inputs.
- **Scope/Inputs**:
  - Environment: Maritime
  - Weather: Clear & Foul (rain)
  - Target: 24 ft (7m) Power boat &
    90 ft (30m) Fishing boat; Head/Stern view
  - Sensor: MWIR, LWIR & TV
  - Operational mode: 90 ft (shore/ship-mounted) &
    1,000 ft elevation (airborne platform)

TAWS Output (LWIR, 90ft, Clear Weather)



TAWS Outputs @ 80% P(Detect)

Inputs/ Sensor		24 ft Power Boat		90 ft Fishing Boat		
		Good Wx	Foul Wx	Good Wx	Foul Wx	
MWIR		2.7 nm	0.3 nm	4.4 nm	0.4 nm	Max
		1.1 nm	0.3 nm	3.4 nm	0.3 nm	Min
LWIR		4.2 nm	0.4 nm	6.4 nm	0.5 nm	Max
		3.1 nm	0.3 nm	3.6 nm	0.3 nm	Min

- Foul Weather significantly degrades IR detection range
- TV sensors are not as vulnerable to weather

TAWS – Findings & Implications

- ✓ **Weather exerts critical impact on IR performance.**
  - ⇒ **EO-IR complementing radar for close-in classification/ identification missions (Rule of thumb: Identification = 60% Detection range).**
- ✓ **No significant performance difference with elevation.**
  - ⇒ **Platform dependent on Deployment/Reaction time.**
- ✓ **TV has significant performance advantage during daytime.**
  - ⇒ **Complementary employment of TV and IR/Image Intensifier sensors is proposed.**
- ✓ **LWIR has better performance consistency than MWIR.**
  - ⇒ **Future advanced EO-IR systems can incorporate both, and have fused output (TV & IR) option, e.g., Raytheon AN/AAS-52.**

Aggregate-Level Modeling

As-Is (Current Radar System)

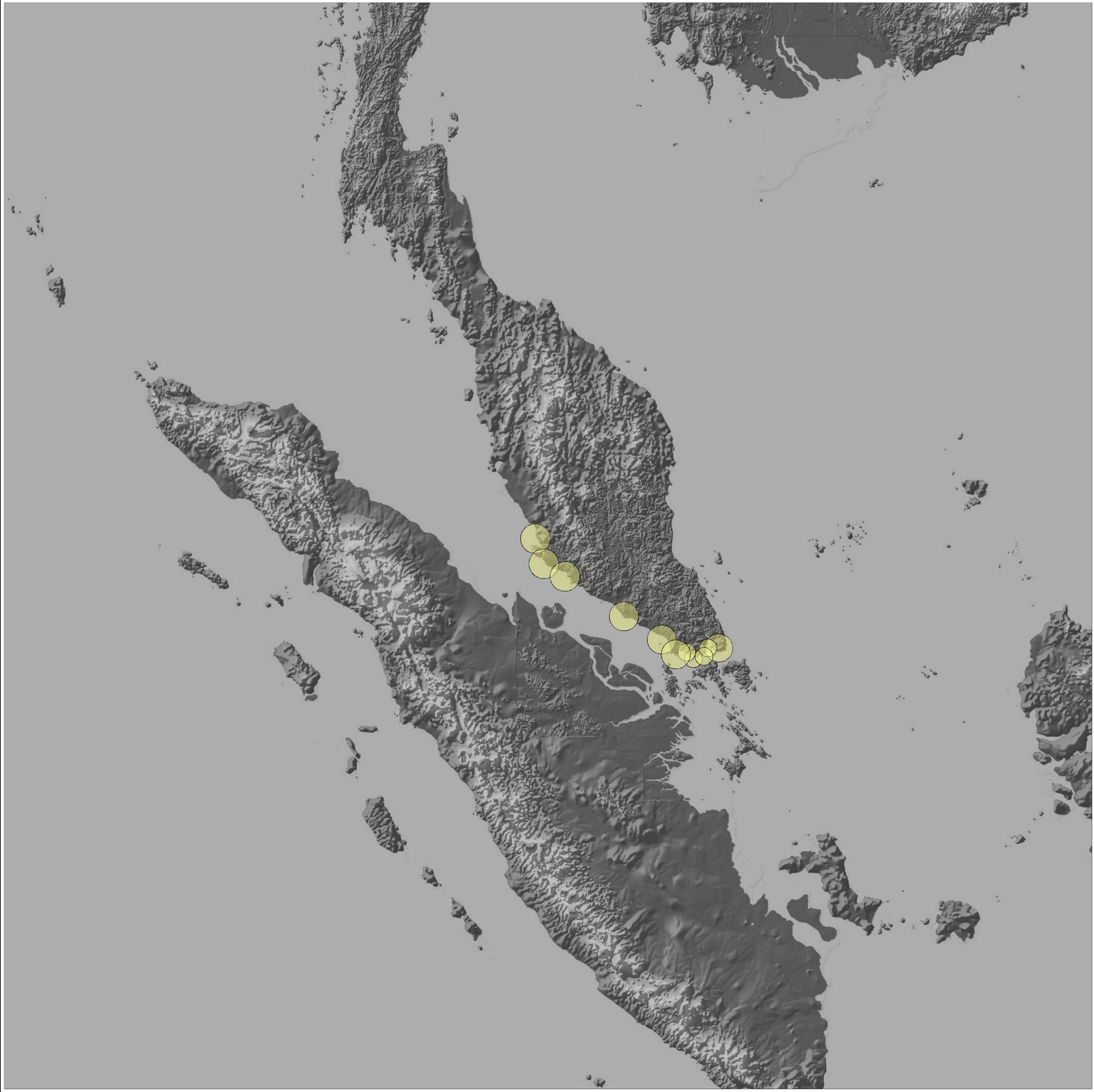
- 12 remote radar stations

Pdet= 0.9

Pfa= 10^{-8}

X-Band

Tgt RCS= 10,000m^2



15 nmi radial coverage

Microwave Radar Coastal Surveillance

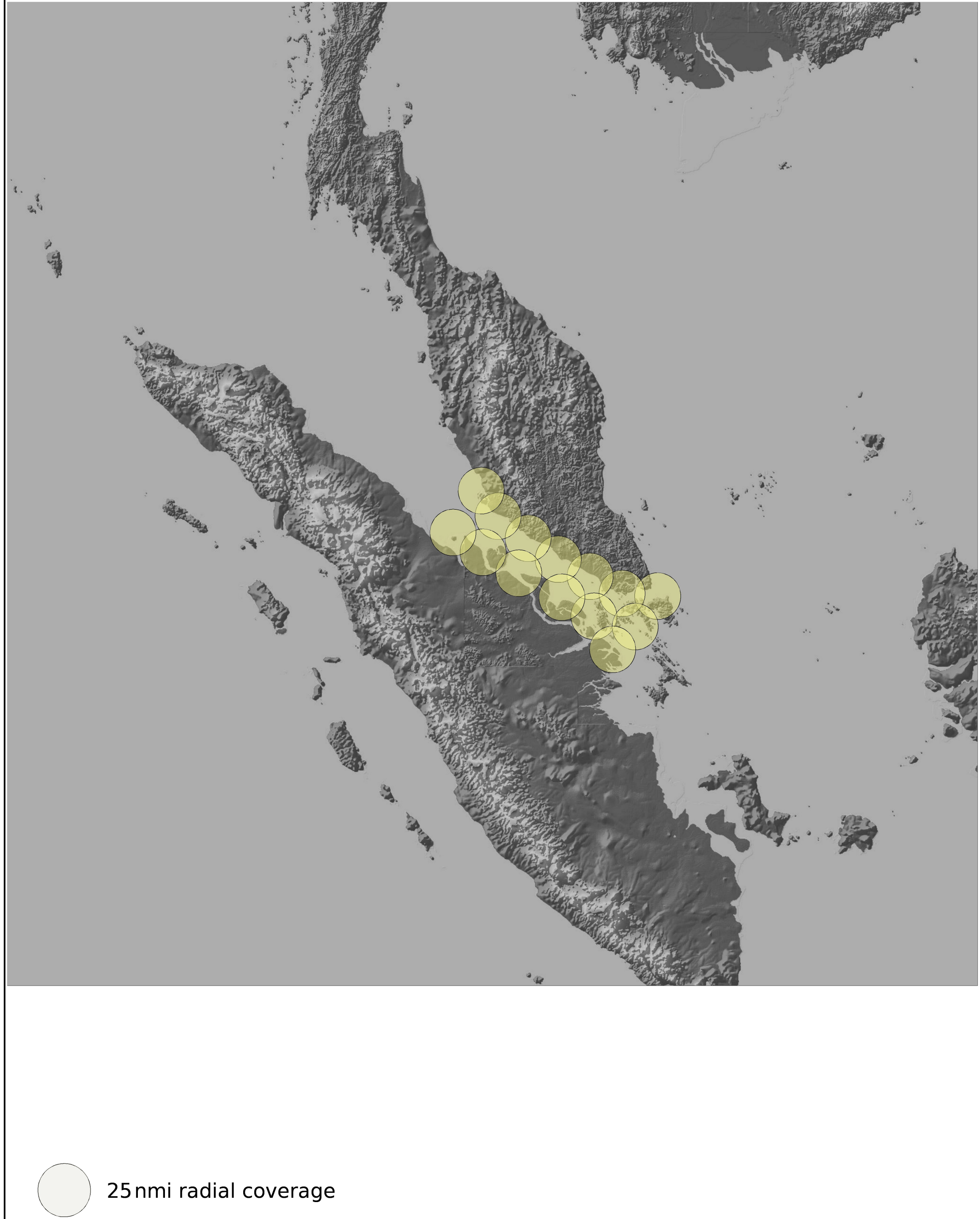
- 14 remote radar stations

Pdet= 0.9

Pfa= 10^{-8}

X-Band

Tgt RCS= $4m^2$



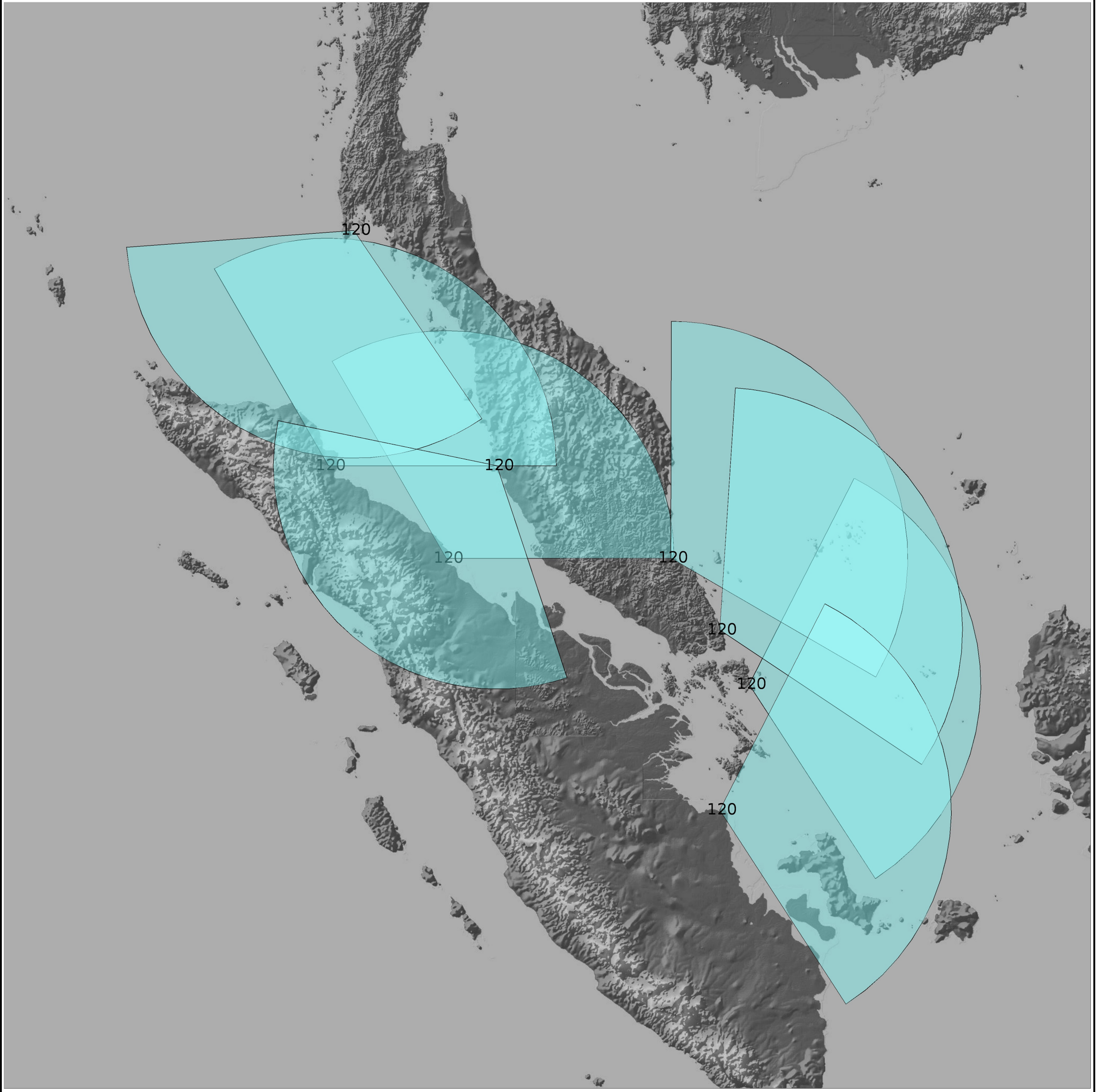
HFSWR

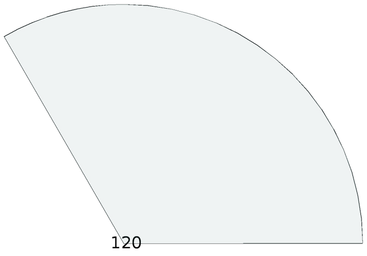
- 6-8 remote radar stations

HF-Band (3-5 MHz)

Tgt Size= >800m²

Wind Speed= up to 30 kt





200nmi radial coverage

MAEAR

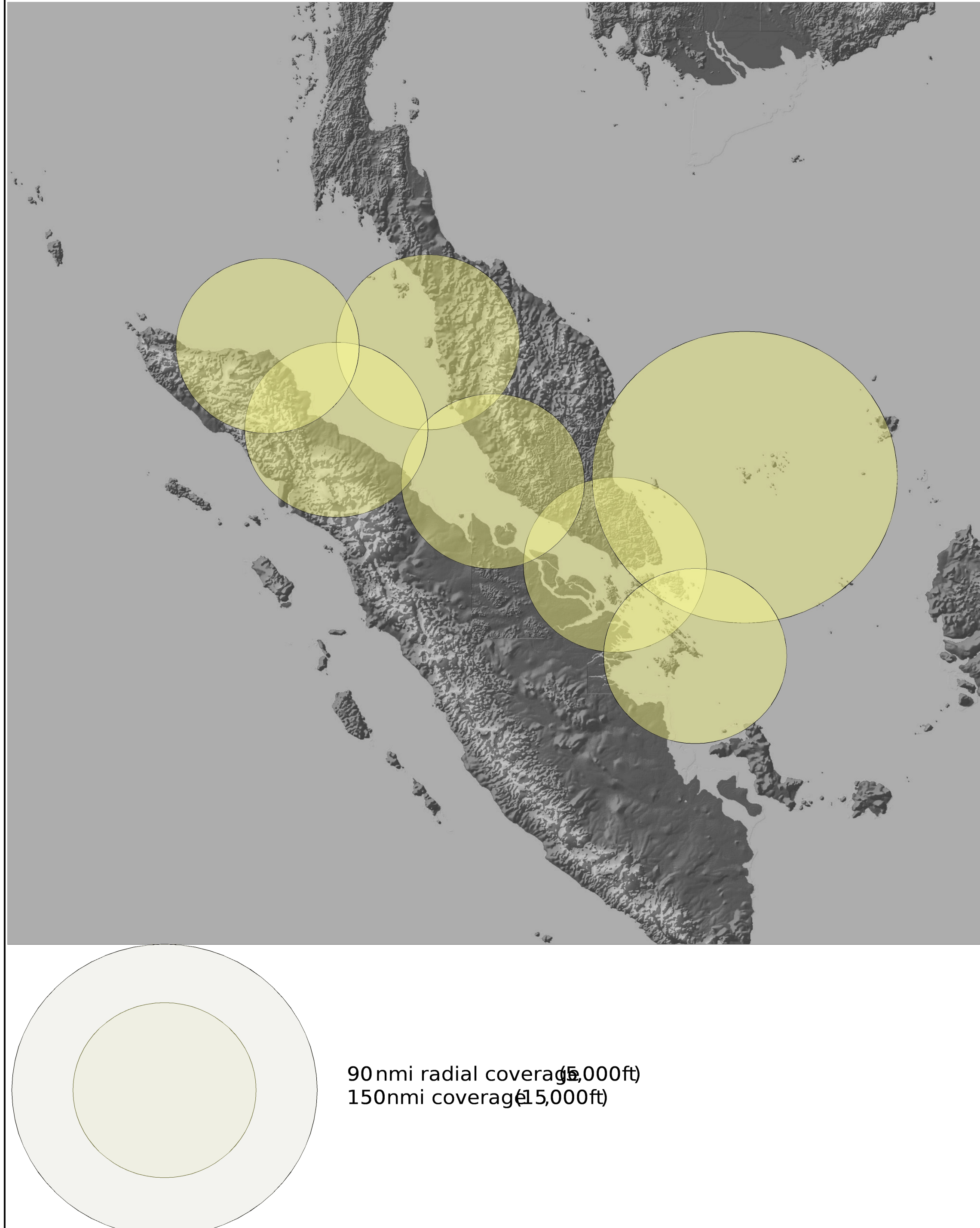
- 6 aerostats at 5,000 ft
- 1 aerostat at 15,000 ft

Pdet= 0.9

Pfa= 10^{-8}

X-Band

Tgt RCS= $800m^2$



MPA

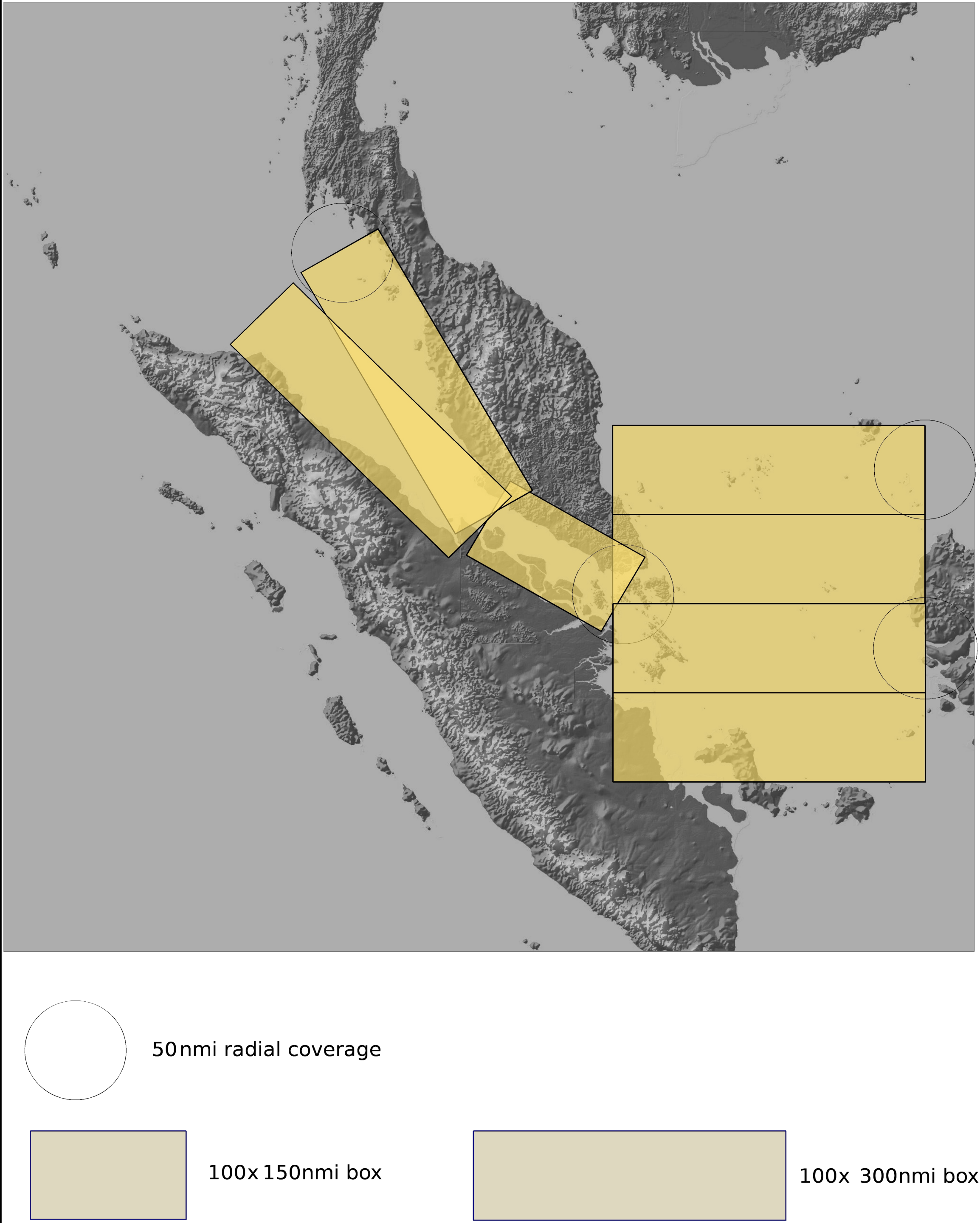
- 4 MPAs (P-3)
- 4 Search & Track boxes
- 50 nmi search mode

Pdet= 0.9

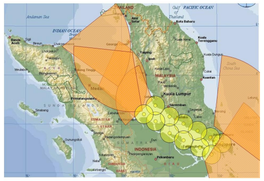
Pfa= 10^{-8}

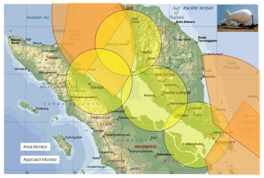
X-Band

Tgt RCS= $800m^2$



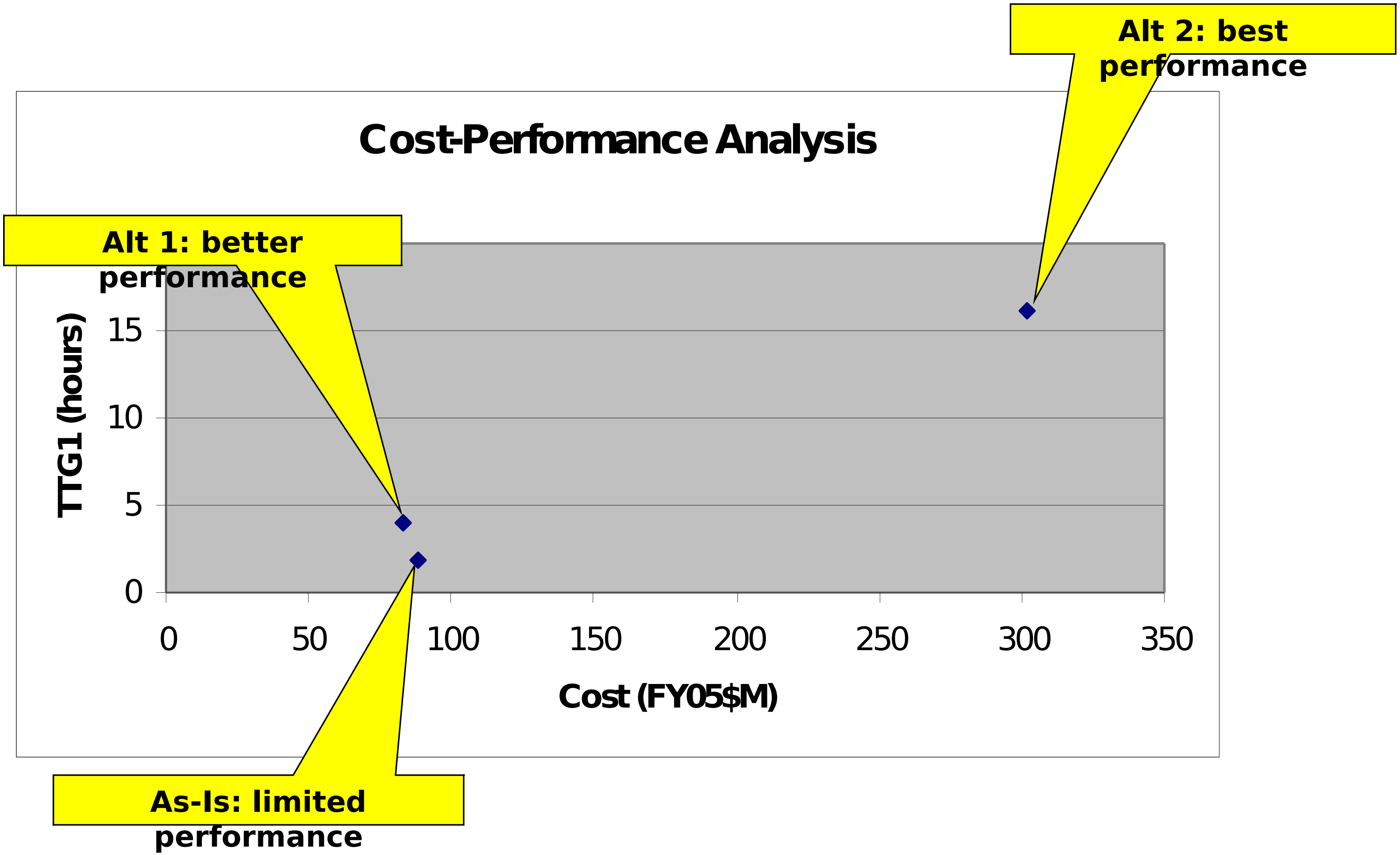
Modeling Results





METRIC / ALTERNATIVE	TTG1 (hours)	Cost (FY05$M)
AS-IS	1.8	88.6
COASTAL MICROWAVE + HFSWR	4.0	83.5
MAEAR + HFSWR	16.1	302.0

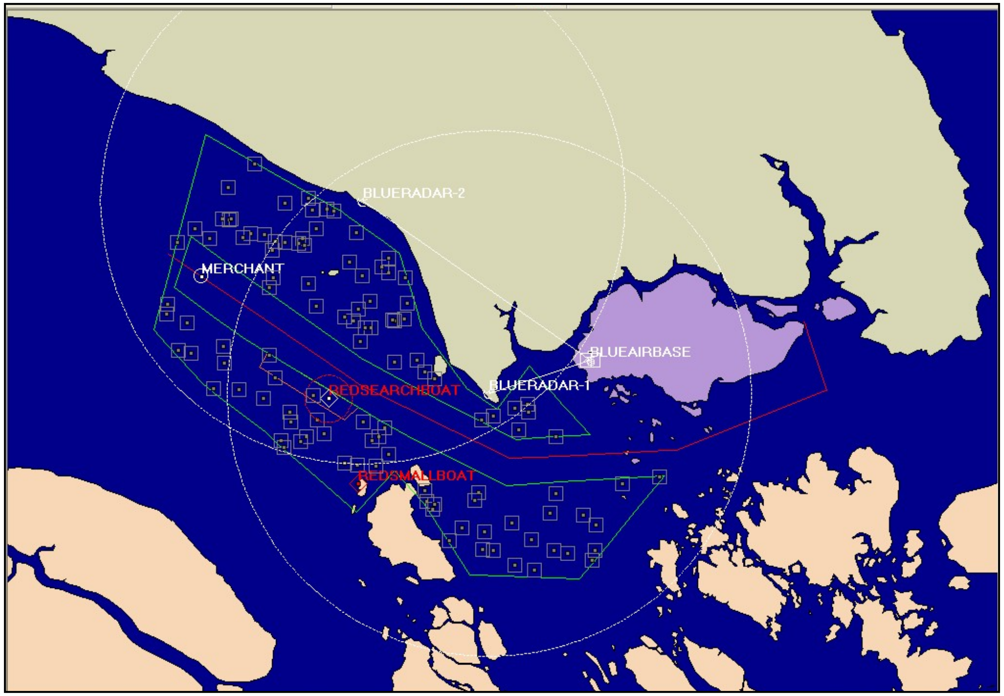
Modeling Results



Naval Simulation System

Naval Simulation System (NSS)

- **Object oriented, stochastic, event stepped simulation.**
- **"Closed-loop".**
- **Collection of low to medium resolution warfare modules.**
- **Selectable MOE output generated as Excel spreadsheets.**
- **Designed to support studies, exercises, experiments, acquisition planning, fleet operations, etc.**



General scenario: (SBA) in approaches to sea lanes near Pulau Assan.

Red Force
- **Hostile small boat**
- **Hostile recon boat**
- **Merchant ship**

Blue Force
- **Coastal radar stations (Detect and Track)**
- **Air Base w/ 3 MPA (EO-IR Class & ID)**
- **C2 Center**

White Force
- **Neutral fishing fleet**

NMS
- **Restricted sea traffic separation lanes**
- **Protection zone around vessel**
- **Speed Restriction**

NSS MOPs and MOEs

Purpose: model and study the impact of selected non-material solutions (procedural) on sensor system performance.

METRIC / FACTORS	TTG1 (hours)	False Alarm Rate
Speed Restriction	f(d)	$f(\delta_{sb})$
Restricted Sea Lane	f(w)	$\rightarrow 0$
Protection Zone Around HVU	f(R)	f(R)

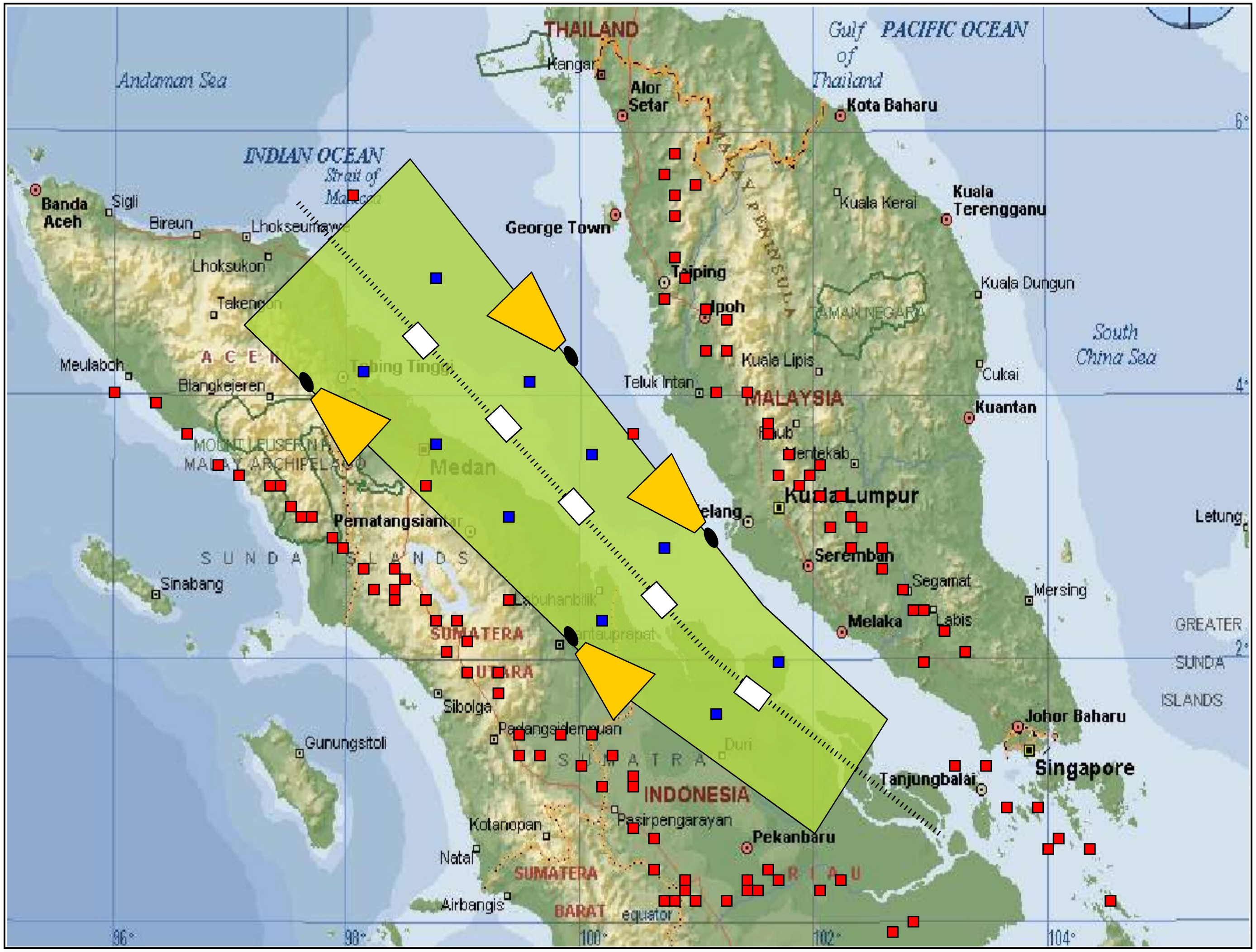
<u>Outputs</u>:

- First detection of target (SBA) by radar.
- First classification/identification of target (SBA) by EO-IR/MPA.
- Number of [operational] False Alarms.
- First Weapon Launch (SBA).

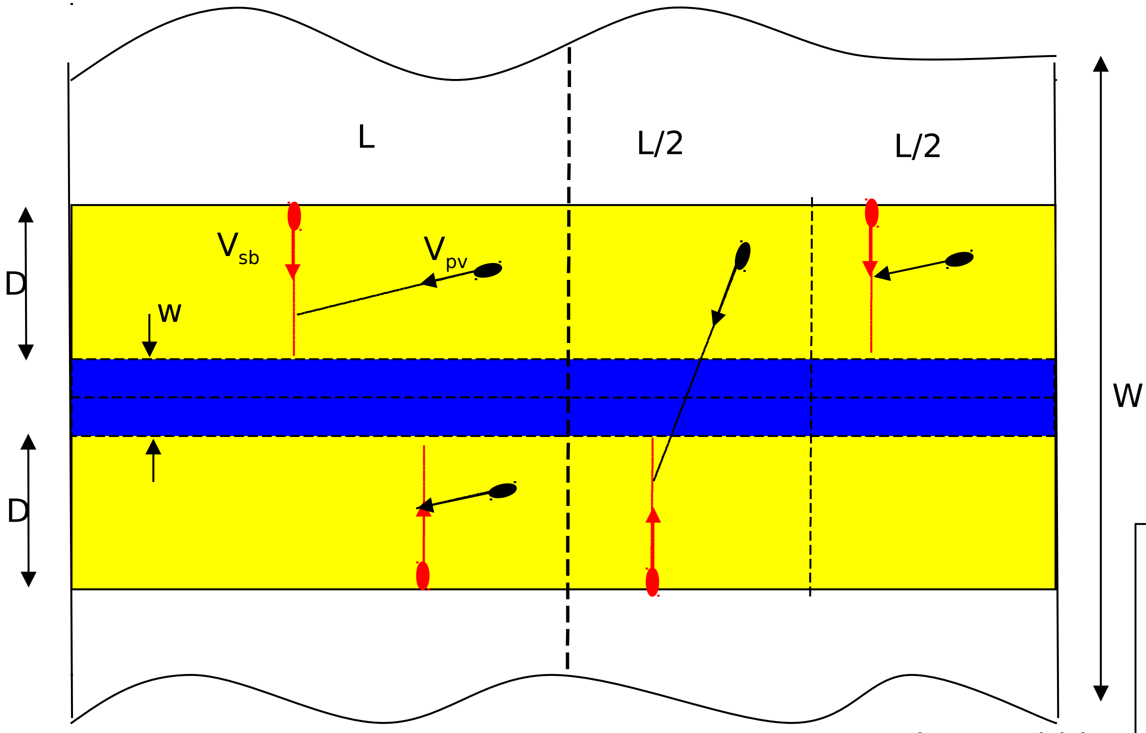
UAVs for HVU Protection

Presenter: LT Jennifer Lorio TDSI - USN

UAVs for HVU Protection



Determining Area of Interest (AOI)



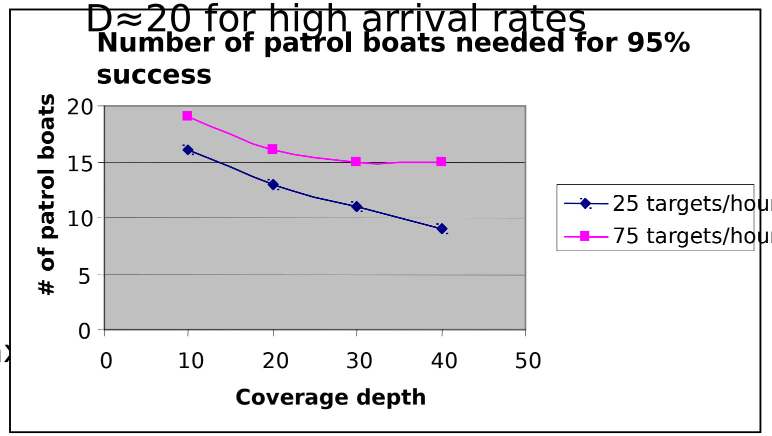
- Sea lanes
- Sensor Coverage
- Strait area

W – Strait width
L – Sector length
D – Depth of Sensor coverage

w – Sea lanes width
V_{sb} – small boat max speed
V_{pv} – patrol vessel max speed

- Single patrol vessel tactic is less effective for chosen rates of arrival; early warning time is not the limiting factor on performance
- There is an almost-linear relationship between the number of patrol vessels and the area of interest for lower arrival rates
- Trade-off between sensing assets and force assets

D≈20 for high arrival rates

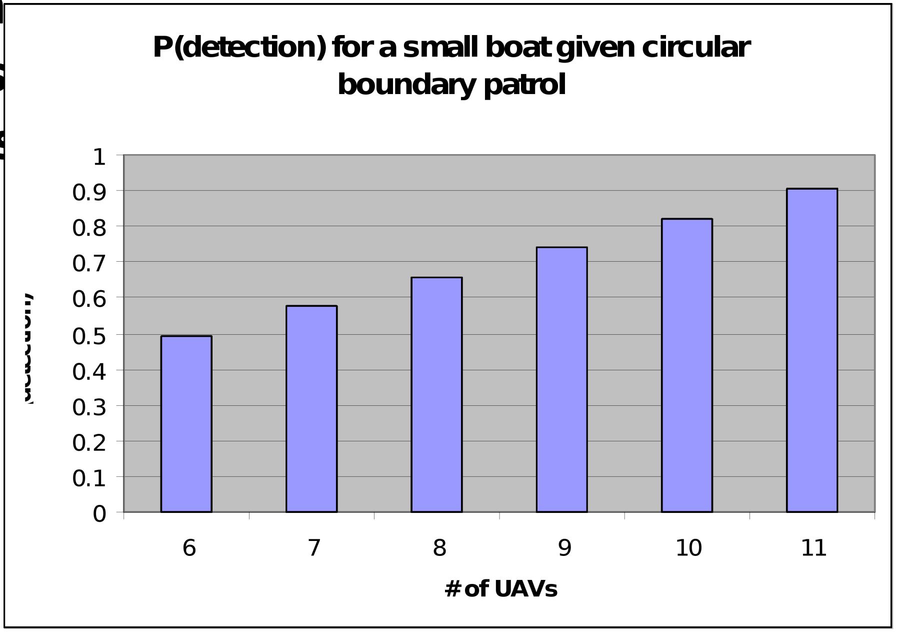


Results and Findings

- Entire Area Coverage – 15 UAVs with perfect sensors

$$SensorCoverageRatio = \frac{sweepwidth * speedoverground * duration}{area\ of\ region}$$

- Boundary patrol $p_{detected} = \frac{2T_d V_c}{d} p_{dr} + \frac{V_{sb} R_f + V_c R_w - 2T_d V_c V_{sb}}{d V_{sb}} p_{dr}$
  - **Circular pattern for length of area of interest – 11 UAVs**
  - **Sector of length L – 8 UAVs**
- Convoy of ships
- Total UAV assets required takes into account MTBF, MTTR, TAT, PMDT, relief requirements



Conclusions/Insights

- ✓ **COTS TECHNOLOGIES EXIST TODAY WITH THE ABILITY TO MEET ALL SPECIFIED REQUIREMENTS FOR BOTH DETECTION & TRACKING AND CLASSIFICATION/IDENTIFICATION.**

- ✓ **DET & TRK (RADAR)**
  - ✓ **MAEAR IS A MATURE TECHNOLOGY. OPERATIONAL AVAILABILITY ISSUES HAVE BEEN MOSTLY SOLVED.**
  - ✓ **HFSWR IS ALSO A MATURE TECHNOLOGY. IMPROVEMENTS (CURRENT EFFORT) IN SIGNAL PROCESSING WILL ENHANCE DET & TRK PERFORMANCE OUT TO THE MAX REQUIRED DISTANCE IN THE SHORT TERM.**
  - ✓ **DUCTING: NOT A CRITICAL ISSUE FOR MARITIME RADAR SURVEILLANCE PERFORMANCE (DEGRADATION).**

- ✓ **CLASS/ID (AIS and EO-IR)**
  - ✓ **AIS CRITICAL (ALL ALTERNATIVES)**
  - ✓ **MPA (WORKHORSE) AND SHIP MOUNTED PLATFORMS**
  - ✓ **LIMITED APPLICATION OF FIXED EO-IR ASSETS (SURVEILLANCE OF CRITICAL POINTS)**

Recommendations

- ✓ **MULTI-SENSOR APPROACH: EXPLOIT SENSOR INHERENT CAPABILITIES TO GET MULTIPLE "LOOKS" OF SAME COI AS IT MOVES THROUGH THE AOR.**

- ✓ **LAYERED APPROACH: INCREASED DEMANDS ON THE SYSTEM (DETECTABILITY, ACCURACY, UPDATE RATE, ETC.) AS THE DISTANCE TO CRITICAL POINTS DIMINISHES.**

- ✓ **"HEIGHT-OF-THE-EYE" IS THE KEY PERFORMANCE DRIVER FOR DET & TRK. INVEST RESOURCES IN EXPANDING THE ENVELOPE HERE.**

- ✓ **CONTINUE TO DEVELOP/EXPLORE**:
  - ✓ **COMPLEMENTING SENSOR DEPLOYMENT WITH NON-MATERIAL (PROCEDURAL) SOLUTIONS TO ENHANCE OPERATIONAL EFFECTIVENESS.**
  - ✓ **CAPABILITIES FOR UAV APPLICATIONS IN THE MDP MISSION.**

Sensors Q&A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